Volume 25 JULY, 1941 Number 7

BULLETIN
of the
American Association *of* Petroleum Geologists

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BULLETIN

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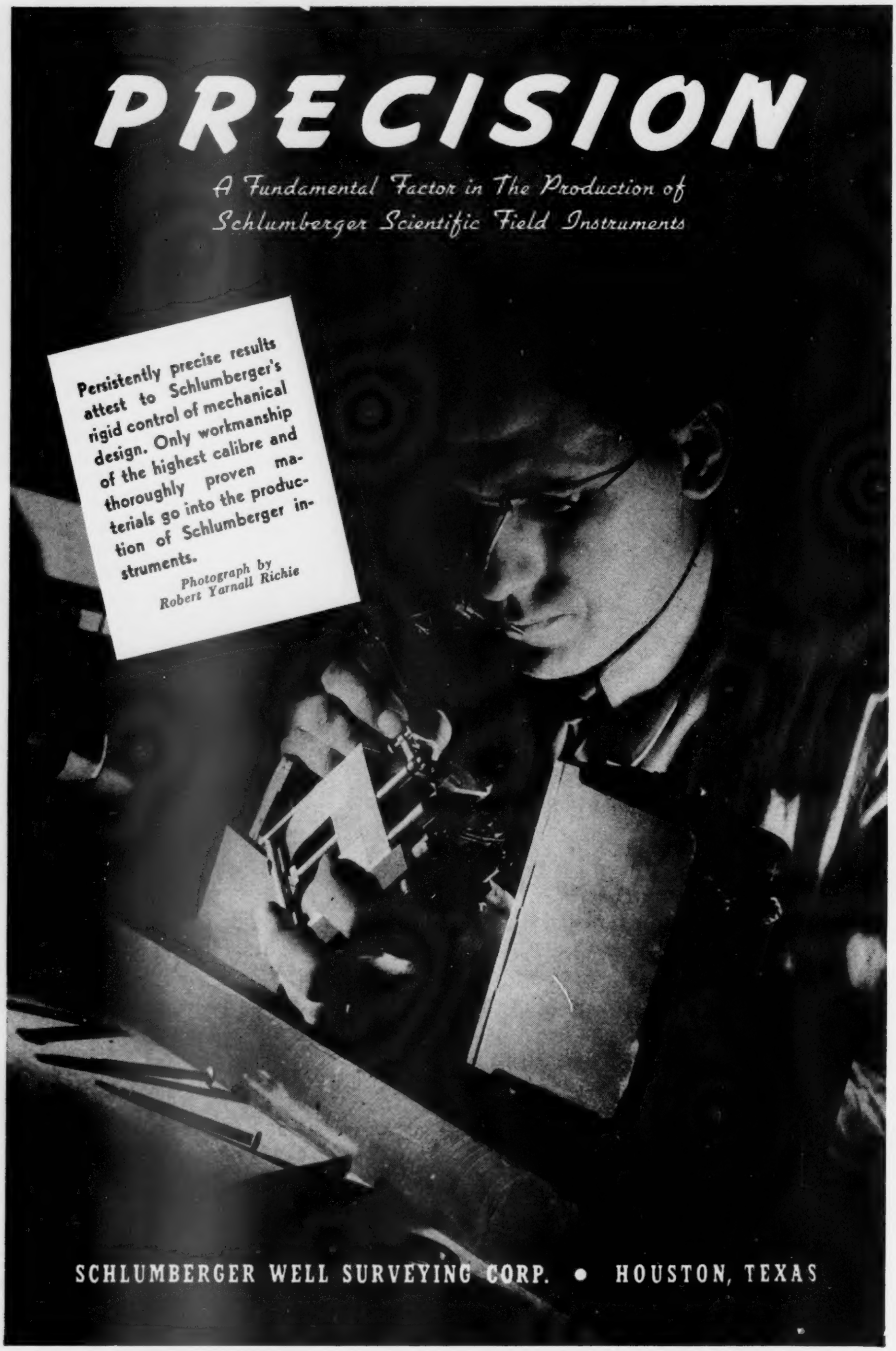

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Volume 25 Number 7

BULLETIN
of the
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

JULY, 1941

REMARKS AT OPENING OF TWENTY-SIXTH ANNUAL MEETING[1]

GEORGE S. BUCHANAN[2]
Houston, Texas

Honorable Mayor Pickett!

On behalf of the American Association of Petroleum Geologists, the Society of Economic Paleontologists and Mineralogists, the Society of Exploration Geophysicists, and the Houston Geological Society, we warmly express our enthusiasm for your cordial welcome to our twenty-sixth annual meeting here met in the City of Houston.

Honorable Mayor, you were chosen to make this address of welcome for two reasons: first, as befitting your rôle as civic leader of this great city and second, because we 400 geologists residing in this city know you would ably extend our heartfelt welcome to our visiting guests.

Turning aside for the moment from the social side of our welcome, we greet you into our geological province with all of its attending problems. At our front door is the finest geological laboratory conceivable, the Gulf of Mexico, and in and around it rests the cradle of our geological thought. We recognize it as a gulf of considerable antiquity. Late Paleozoic orogeny helped define its borders and in early Mesozoic time a rather completely desiccated Gulf of Mexico was the stage for long uninterrupted salt deposition. Factors contributing to this unusual concentration of salt were many: complete desiccation from the open seas, aridity of Triassic and Jurassic climates and a carry-over concentration of Permian salts on the border lands of this gulf. Recognized arms or embayments of this desiccated ancestral gulf in which thick salt was deposited were Tehuantepec, Corpus

[1] Response to the welcome extended the Association at Houston, April 2, 1941. In the absence of Mayor Neal Pickett, Colonel Norman H. Beard greeted the Association.

[2] President of the Houston Geological Society, 1524 Esperson Bldg., Houston, Texas.

Christi, East Texas, Interior Embayment of Louisiana, and several narrow arms extending into Mississippi. Following this salt deposition the history through Lower and Upper Cretaceous times and all through the Tertiary has been one of gradual filling-in of sediments along the borders of this deep ancestral gulf. Conditions of sedimentation along the strand lines of the Gulf of Mexico to-day probably duplicate rather closely much of the sedimentation in the past. Many living marine plant and animal organisms live under much the same conditions as the fossil remnants we find in our Tertiary section. From a standpoint of structural geology the forces exhibited by the plastic flowage of this ancient salt have produced most interesting and varied expressions of folding and faulting in the overlying sediments. Normally the weight of the sediments deposited along the margins of the ancestral Gulf of Mexico would have already resulted in profound diastrophism and caused isostatic adjustments within the plutonic rocks had it not been for a cushion of salt. The mother salt through flowage helped distribute weight and bring loaded areas into equilibrium.

In addition to our regular technical meetings, under the direction of Perry Olcott, we have arranged this year a series of events which we hope will engage your interest in our problems: the technical exhibit under the direction of Paul Weaver, the research laboratory tour under the direction of W. A. Clark, a series of field trips under the direction of J. A. Culbertson, and pamphlets under the direction of C. D. Lockwood, Wallace Thompson, and J. Brian Eby. These men and members of their committees, and the other committee chairmen and members of their committees, have all worked ardently and faithfully under the able direction of Mr. Alexander Deussen, general chairman for all convention arrangements. To him and to all committee chairmen and committee men and to all members of the Houston Geological Society I wish to express my appreciation for the splendid coöperation which has been exhibited.

I now turn the meeting over to Dr. L. C. Snider, president of the American Association of Petroleum Geologists.

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PETROLEUM GEOLOGISTS IN THE NATIONAL DEFENSE PROGRAM[1]

L. C. SNIDER[2]
Austin, Texas

Under the present disturbed world conditions it is thought better that the presidential address at this meeting should depart from the usual type dealing with some scientific phase of our profession, and instead attempt to acquaint the membership fully as to what has been done, and is being done, by the Association in order to make the services of petroleum geologists of the maximum possible benefit to the nation.

So far the only result of our efforts has been some assistance we have been able to give in distributing the questionnaires and technical check lists in geology for the National Roster of Scientific and Specialized Personnel which all members of the Association have received or, at least, should have received.

The plan for a classification of scientific and technically trained workers originated with the National Research Council. About May 1, 1940, the chairman of the Council addressed a letter to the chairman of the Division of Geology and Geography, pointing out the British organization of such a roster and the possible advantages of a similar roster in the United States, and inquiring as to the possibilities of the Division and its affiliated societies preparing something of the sort for its field.

The chairman of the Division proposed as a tentative plan that the Division prepare a questionnaire to be distributed to their members by the Geological Society of America and the American Association of Petroleum Geologists. I sent the correspondence concerning this plan to A. I. Levorsen, our representative on the Division of Geology and Geography of the National Research Council, suggesting that he discuss the project with the business manager of the Association and determine what sort of plan would be feasible for such a roster of the Association and expressing my assurance that the executive committee would coöperate in any plan which they might decide upon to further the purpose of the National Research Council.

After considering the project carefully, Levorsen, at the end of May, 1940, recommended that the Association coöperate fully with the National Research Council in the survey and suggested various

[1] Address of the president, twenty-sixth annual meeting of the Association, Houston, April 3, 1941.

[2] Department of Geology, University of Texas.

plans for conducting it which were necessarily tentative inasmuch as those finally decided upon must fit in with those made by the Council to cover all fields of science and technology. It was Levorsen's opinion that better results would be secured if the questionnaire for our membership were prepared and distributed by the Association and the returns evaluated and catalogued by a committee of its members rather than if this work were to be done by parties not intimately acquainted with our field of work. The chairman of the Division of Geology and Geography was informed of these conclusions, and that the Association would be glad to coöperate fully in the preparation of the roster according to any plan the National Research Council might adopt.

During June, 1940, I secured the consent of the executive committee to appoint, if it seemed advisable to do so, a special committee whose duties should be to arrange the details of our participation in the preparing of the roster. Since there was no definite plan under consideration at that time, there was then no reason for appointing such a committee, and no circumstances have arisen since which seemed to make its appointment advisable.

Early in July the Geological Society of America and the Association were informed through the National Research Council that plans for the census should be held in abeyance as "plans are now definitely under way for undertaking a national registry of scientific and expert personnel of the United States under Government auspices." The undertaking was placed in charge jointly of the National Resources Planning Board and the United States Civil Service Commission. The Social Science Research Council, American Council of Learned Societies, American Council on Education, and National Research Council were called into consultation.

The new project was organized as the National Roster of Scientific and Specialized Personnel, under the joint direction of the National Resources Planning Board and the United States Civil Service Commission, with Dr. Leonard Carmichael, president of Tufts College, as director of the Roster, and Mr. James C. O'Brien of the Civil Service Commission as executive officer. The National Research Council collaborated in the field of science and technology, with Dr. John S. Nicholas, Sterling Professor of Zoölogy at Yale University, as the Council's representative on the National Roster Committee.

Mr. J. P. D. Hull, as business manager, and myself, as president of the Association, were asked to serve on an Evaluation Committee in the field of Geology and Geography. We both accepted but, so far as I know, the committee has had no business brought before it.

The Roster adopted the plan of a general questionnaire applicable to all scientists and technically trained men with technical check lists for the different specialized fields. The information given on these lists is to be transferred to elaborately planned punch-cards by means of which it is believed that those qualified to fill a certain need in the national service can be located almost immediately. In a report giving the progress of the Roster to November 15, check lists for eleven fields are reported as having been printed; for three fields as having been approved; and for twenty-three as being "in process." Geography was among the fields given as having its check list approved, but geology was not mentioned.

However, in conversation with officials of the Geological Society and particularly in a conference on October 14 with the National Research Council's representative on the National Roster, it developed that the Geological Society of America was actively at work on a check list to cover the Society and its affiliates. Evidently, those in charge of the Roster had felt that returns from this group would cover the field of geology satisfactorily, but had been informed by the officials of the Society that it would not do so and also that the technical check list they were preparing did not cover the field of petroleum geology satisfactorily. I informed the Council's representative that at least 2,500, and probably 3,000, of our members would not be reached through the mailing list of the Geological Society or any other organizations which were preparing check lists; also, that the field of petroleum geology had too many specialized ramifications for the qualifications of our members to be of service in a national emergency to be adequately set forth on a technical check list prepared for the general field of geology, and that petroleum geology should have a separate check list. I was instructed to wait until the executive officer had been informed of my views and his decision obtained.

Unfortunately, I evidently did not make myself clear on the point of a separate check list, for while it was recommended that the Association membership be added to the list of those to whom the geology check list should be sent, the distinct impression was given, as I did not discover until considerably later, that the general geology check list would be satisfactory.

Having had no further information or instructions in regard to this subject, I wrote the National Research Council's representative on the Roster committee in the latter part of January, 1941, to determine whether or not any progress was being made in securing a special check list for petroleum geologists and was informed that cards and envelopes addressed to the members of the Association had already

been obtained through the Tulsa office and were to be mailed immediately—in fact were probably being mailed at that time. These envelopes carried the general questionnaires and the general geology technical check lists which each member should have received.

Under these conditions, it was thought best to withdraw the request for a special check list and leave the situation as it was until later consideration might show a way to get the qualifications of petroleum geologists more satisfactorily before the governmental agencies and others who might have need for their services in the defense program.

It should not be considered that our efforts in this regard have reached a final stage. I received only last week a letter from Walter H. Bucher, chairman of the Division of Geology and Geography, National Research Council, of which, with his permission, I quote a large portion.

> I am writing to tell you of a plan which took shape after my disappointment over the organization of the so-called "Evaluating Committee" attached to the National Roster, and which was perfected with the valuable help of Mr. Levorsen. At present, I am the head of each of several committees in Geology, Geophysics, and Geography, which are expected to pass on the suitability of men drawn from the Roster for specific jobs. I wish to place before Dr. Harrison, the Chairman of the National Research Council, the proposition to replace the present arrangement by another more flexible one. The plan is as follows: To ask the presidents of each of the large organizations in Geology, Geophysics, and Geography, to stand ready to appoint a committee of a few competent men in any specific field for which a request for judgment shall come to me. These committees would not be designated beforehand but would be created on the spur of the specific request in accordance with its character. Such a committee should consist of a few men and could be set functioning within 24 hours for the specific purpose by wire. Any request would be routed through me to the president of the respective organization and handled by him according to this scheme. I should like to have the members of the present evaluating committees, designated as such by Dr. Harrison, notified of this change and assured of their place in this scheme whenever a request for action comes.
>
> In addition to this, I am about to ask for the creation of a Committee on the Place of Geologists in Modern Warfare. This committee shall consist of three members whose task shall be: (a) to prepare a bibliography of important American and European papers and books on the subject, including at least tables of contents of several books that appeared in Germany on military geology; (b) to write or solicit the writing of articles on the rôle of geologists in modern warfare, to be published in technical and possibly also in popular magazines, and designed to call attention to the special uses to which men with geologic training can be placed. I wish to mention especially the acquaintance with methods of triangulation, and all other means of determining factors of topography. Many military men do not associate the word "Geologist" with this type of training which is of such high value in field operations.

Chairman Bucher closes his letter with a request for the Association's participation in each of these plans if they are adopted by the roster.

The decision as to whether or not to agree to Chairman Bucher's request will rest with the incoming rather than the present executive committee, but I see no reason to doubt that the Association will assist in performing the services suggested, as well as any others in which we may have an opportunity to partake.

Undeniably some feeling of disappointment at the lack of more positive results is present in the minds of all those who have had any part in the preparation of the geological section of the National Roster of Technical and Specialized Personnel.

Probably, however, some such feeling is inevitable in the consummation of a project of such magnitude. The November report of the executive officer of the Roster, referred to previously, mentions some of the difficulties of arranging offices in a capital city already overcrowded, securing the personnel to handle the mechanical work of filing the questionnaires and technical check lists and of designing the punch-cards and transferring the data to them.

When this fundamental work is completed, it seems only logical to expect that more and more explicit classifications in various fields will be undertaken. The Association will certainly do everything possible to obtain such a classification of petroleum geologists.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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MICROPALEONTOLOGY—PAST AND FUTURE[1]

CAREY CRONEIS[2]
Chicago, Illinois

ABSTRACT

This paper traces the rise of interest in microscopic fossils, especially from the sixteen sixties when Leeuwenhoek's development of the forerunner of the microscope made their detailed study possible, through the several centuries of their sporadic investigation, chiefly by isolated individual scientists in the interests of pure research, to the birth of the utilitarian science of micropaleontology a quarter-century ago. The developmental phases of the science are outlined, and the progressive multiplication of the micropaleontologic groups studied is considered.

The origin and growth of micropaleontology as a subject in university curricula are reviewed, and suggestions are made for the future expansion and improvement of training in this special field. In addition, brief consideration is given to the general academic background the prospective paleontologist should acquire in order best to serve his science as well as prove most valuable to the organization which purchases his services.

Finally the future of the science of micropaleontology is analyzed, and suggestions are made for the direction of efforts into lines of investigation which may prove profitable in enlarging the scientific scope and significance of the field, and thus in enhancing its commercial significance.

INTRODUCTION

Although you can not find the word in the Oxford University English Dictionary, Micropaleontology has come of age both commercially and academically. Even Webster's Unabridged lexicon which defines micro-everything else, only grudgingly recognizes the existence of this husky scientific youngster by including its name in a list of micro-this and thats. It therefore seems necessary to probe into the ancestry and weigh the prospects of this relative newcomer in the growing society of geological sciences.

In doing so the writer is not unmindful of the fact that in scientific endeavor the historical approach has long been considered[3] just about the lowliest approach of all. Indeed, if any investigator is held in less repute than the scientist who mulls over his subject's past, it is he who indulges in prophecies of its future, for, in scientific protocol, the antiquary has always been seated next to the augur at the foot of the table. In this paper the writer not only proposes to be both antiquary and augur, but he may, like most good microstratigraphers, even practice a sort of modern psephomancy—which, appropriately enough, is the ancient art of divination by drawing pebbles from a heap.

[1] Fourteenth annual address of the president of the Society of Economic Paleontologists and Mineralogists before the joint meeting of the American Association of Petroleum Geologists, the Society of Economic Paleontologists and Mineralogists, and the Society of Exploration Geophysicists, at Houston, April 3, 1941. Manuscript received, May 5, 1941. Reprinted, with permission, from the *Journal of Paleontology.*

[2] Walker Museum, University of Chicago.

[3] But chiefly by those who do not know their subject's history.

Actually it is the purpose of this paper to demonstrate, among other things, that commercial microstratigraphy, like most industrial advances, developed out of, and will continue to advance because of, cloistered scientific research. Although to-day *academic* micropaleontology is in large part dependent on *commercial* micropaleontology, on the whole, the development of the subject is another valid proof of the fact that science *discerns* the laws of nature and industry *employs* them, for the good of all mankind, whether it be in the petroleum business or in any other kind of business.

EARLY SCIENTIFIC BACKGROUND FOR THE DEVELOPMENT OF MICROPALEONTOLOGY

Although the economic importance of microfossils has been developed largely during the past quarter of a century, the Foraminifera, at least, have been recognized both as "natural" curiosities and as objects of scientific interest for centuries. The various approaches to the study of this group were roughly divided into eight main time divisions by Professor Galloway (1928) in the first presidential address before the Society of Economic Paleontologists and Mineralogists, and the subject requires only brief attention here.

Very little was *actually* known about the Foraminifera before the time of Beccarius (1731), although "nummulites" early attracted attention, presumably on account of their relatively large size. One of the first writers to note them was Herodotus in the fifth century B.C., and Pliny the Elder also takes cognizance of the type in the first century A.D. Strabo, the historian, mentioned their resemblance to *Ervum lens*, the Eurasian plant known as the lentil; and he noted that, since they were found near the bases of the Egyptian pyramids, they were supposed, he thought erroneously, to be the flattened pea-like food dropped by the workmen, which afterwards had become petrified.

Much later many other observers gave descriptions of "nummulites," notably Agricola in 1556; the talented Swiss of Zurich, Conrad Gesner (Fig. 1), who figured them in the first true paleontological publication (1565); Hooke in 1667; M. Lister in 1678; Scheuchzer (Fig. 2) in 1687–8?, who centuries after Strabo still described and figured them as *lentes lapideae striatae* or striated stone lentils; Edward Lhuyd in 1699; and Brueckmann in 1727, who gave a figure of his *lapidus numismalis*, or stone coin. In 1724 Louis Bourguet published his all-too-little known "Traite des Petrifications" in which he refigured some of Scheuchzer's specimens, under the title *Pierre lenticulaire* (Fig. 3). Bourguet also gave an entire plate (Fig. 4) to the illustration of small fossils, some of which the modern micropaleontologist

FIG. 1.—Conrad Gesner in 1565, the year of his death. After Adams.

would probably classify vaguely as "echinoderm fragments." Most of these figures, which Bourguet borrowed from Lang and Scheuchzer, are confidently identified as *fruits* and *fleurs de Plantes marines*, or as *fruits de coralloides*, or *fleurs de cariophilloides!*

As so commonly happens in scientific progress a notable advance in one field opens undreamed-of vistas for exploration in other and seemingly entirely unrelated subjects. The development of the microscope was such an advance in optics which of course opened new

FIG. 2.—J. J. Scheuchzer, 1672–1733, shortly after publishing the description of *Homo Diluvii Testes*. From *Itinera Alpina* (London, 1708), in writer's collection.

avenues for research in many fields other than geology. The very earliest beginnings of the microscope probably date from the Middle Ages, but the first crude compound instrument was that of Zacharias Zanser, a Dutchman who made his magnifier in 1590. It was not until after Anton Leeuwenhoek (1632–1723) constructed his microscopes

in the 1660's and actually began to look at micro-organisms, however, that the stage was set for the examination of the more minute Foraminifera.

One of the first to do such research was Beccarius (J. Beccari), of the early North Italian school of micropaleontology, who, in 1731, described the various minute shells from the yellow Pliocene sands

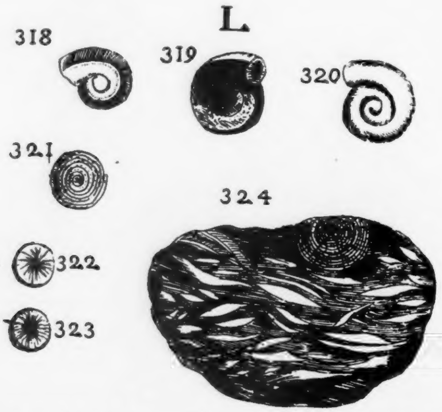

FIG. 3.—Plate 50 of Louis Bourguet's *Traité des Petrifications*, showing in figures 318–320, "Petit ver de mer," in figures 321–324, "Pierres lenticulaires"! University of Chicago Library.

near Bologna. Beccarius also mentioned the Adriatic shore sand of Rimini which later yielded many Foraminifera to another investigator, Janus Plancus (Giovanni Bianchi). Plancus published his memoir in 1739, and stated he had found as many as 6,000 specimens in a single ounce of the Rimini sand.

These early observers, it should be noted, classed many of the minute Foraminifera as cephalopods or "worms" under the supposition that they were small individuals of the larger marine shells. Nevertheless, by the middle of the eighteenth century, as Augustino Scilla graphically points out in the frontispiece to the revised edition of his *Corporibus Marinis* (1759), "perception *was* beginning to direct idle speculation in paleontologic work." This was a real advance and one badly needed after Scheuchzer's straight-faced description of a Miocene salamander as *Homo Diluvii Testes*, or the man who witnessed the flood, and Johann Beringer's (1726) *Lithographiae würceburgensis*, in which he described as *bona fide* organic remains all sorts of objects his students had surreptitiously made to confound him. It is a sober-

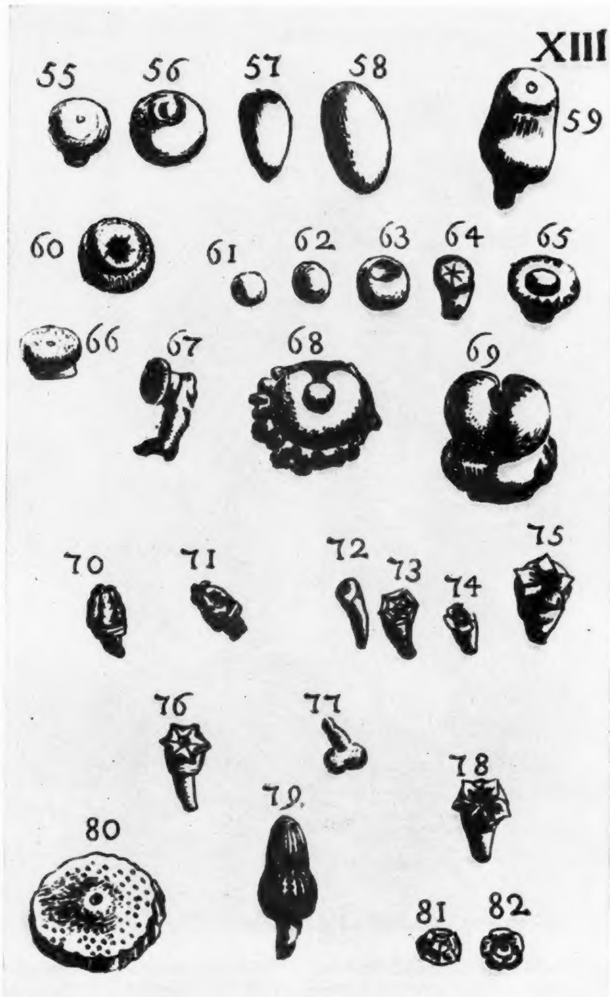

FIG. 4.—Plate 13 of Louis Bourguet's *Traité des Petrifications*, showing "Espéce de fruits de coralloide," "Fruits et fleurs de plantes marines," "Alcyons de figure bizarre," "Apophyse de plante ou d'animal de mer," and so forth. University of Chicago Library.

ing thought to recall that both Scheuchzer and Beringer were outstanding men of science in their day, and that two centuries later we

FIG. 5.—"Perception directs idle speculation," a frontispiece made in 1751 for Augustino Scilla's *Corporibus Marinis.* University of Chicago Library.

may be placing great reliance in popular modern scientific concepts which ultimately will be proven as man-made and unrealistic as Beringer's faked fossils.

The figures and descriptions of Foraminifera given by Plancus (1739), Gualtieri (1742), and Ledermüller (1760–68) were assigned specific names by Linnaeus in the 12th edition of his *Systema Na-*

turae (1766–67), and in Gmelin's edition of the same work (1788–93), so that with the establishment of the binominal system in the classification of microfossils the nomenclatorial problems were somewhat simplified, and work in the field was correspondingly accelerated.

The next significant advance was made by Lamarck (1812) who in his "Cours de Zoölogie" referred the Foraminifera either to the

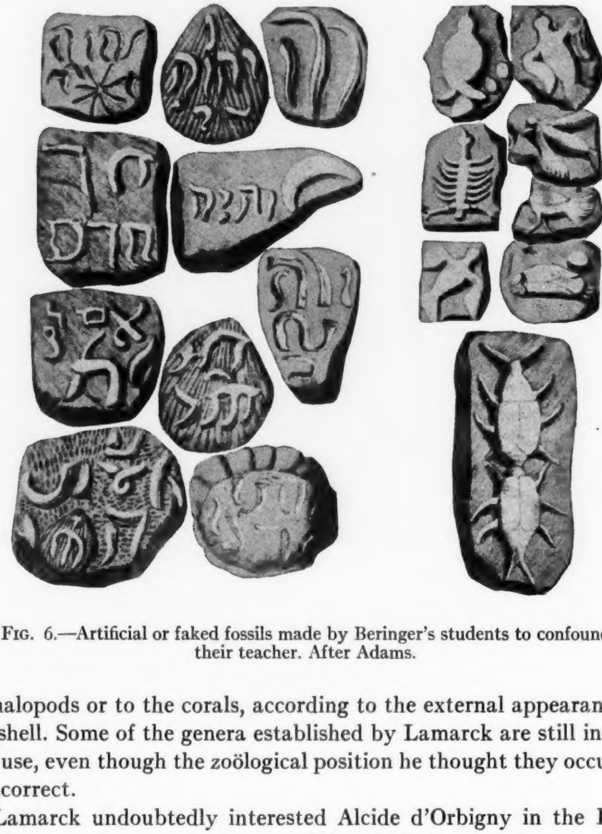

FIG. 6.—Artificial or faked fossils made by Beringer's students to confound their teacher. After Adams.

cephalopods or to the corals, according to the external appearance of the shell. Some of the genera established by Lamarck are still in general use, even though the zoölogical position he thought they occupied is incorrect.

Lamarck undoubtedly interested Alcide d'Orbigny in the Foraminifera, and in 1826 the latter published his first of a long series of papers on the subject. Although it was not until 1835 that Felix Dujardin demonstrated that the Foraminifera belong to the Protozoa, d'Orbigny's work really inaugurated the modern approach to the study of the group. Since his time 1,000 different authors have pub-

lished approximately 5,000 papers on the Foraminifera. Moreover, there have been proposed close to 1,500 generic names and approxi-

FIG. 7.—Gualtieri (Nicolaus Gualterius) as he appeared in 1735, when he was starting to work with the Foraminifera. From the writer's collection.

mately 18,000 specific designations, so that their mere cataloging requires (Ellis and Messina, 1940) 30,000 pages!

CHRISTENING OF THE SCIENCE

Micropaleontology, which with its sister subfield of microlithology comprises the science of microstratigraphy, shares with most other sciences the distinction of being, in the broadest sense, much older

FIG. 8.—Blind Lamarck, 1744–1829, in his Jardin des Plantes days. After von Zittel.

than its name. Professor Galloway is of the opinion that the first use of the word, micropaleontology, may have been by Arthur H. Foord in a paper on Bryozoa and corals entitled "Contributions to the Micro-Paleontology of the Cambro-Silurian Rocks of Canada," which appeared in Geological and Natural History Survey of Canada, 1883.

The title probably was written by Alfred R. C. Selwyn, then director of the Survey of Canada, inasmuch as the identical heading was used

FIG. 9.—Alcide d'Orbigny, 1802–1857, as a young man in his early thirties. After Galloway, from *Voyage Pittoresque dans les Deux Amériques*, Paris, 1836.

in Part II of the same work (1889), dealing with Bryozoa and Ostracoda, under the authorship of E. O. Ulrich. Professor Schenck and the writer both feel certain that the term had a somewhat earlier usage

but a definite older reference to prove the point can not at the moment be cited. It is true, however, that Ehrenberg as early as 1854 employed the term "microgeology" in essentially the same sense as we now use the word micropaleontology.

Micropaleontology has doubtless been used informally on many occasions before it began to appear consistently in the literature. Professors Galloway and Coryell at Columbia University have used the term in its modern connotation since 1919, and as early as 1923 formal courses in the subject were given both at Columbia University and at the University of Texas.

The Columbia University *Bulletin of Information*, Division of Geology, Geography and Mineralogy, for 1924-25, carried the following announcement.

> Geology 207–208.—Micropaleontology. . . . Professor Galloway.
> The principles of Paleontology, classification and nomenclature, the use of paleontological literature, and the identification of small forms with the microscope. Special attention is given to the use of minute fossils, mainly Foraminifera, Bryozoa, and Ostracods, in the solution of stratigraphical and structural problems.

EARLY BACKGROUND FOR BEGINNINGS OF COMMERCIAL MICROPALEONTOLOGY

Foraminifera from well cuttings were used at least as early as 1877 when Felix Karrer determined the age of the strata penetrated by an Austrian water well drilled near Vienna to be middle Miocene. In 1884 H. J. Eunson used well cuttings to determine the age of rocks beneath Northampton, and a little later in the same year J. W. Judd published his all-too-little known symposium on the results of the "Deep Boring at Richmond." T. R. Jones contributed to Judd's symposium by describing both the Foraminifera and Ostracoda from the "Boring." These micropaleontologic objects he called "microzoa," and he was able to identify them as Jurassic in age. Other studies of well cuttings, the microfossils of which were used for correlation purposes, were published by W. Howchin in 1891, F. Chapman in 1900, and by R. J. Schubert in 1904. Howchin used Tertiary Foraminifera in determining the age of strata encountered in the Kent Town Bore, Adelaide, Australia, and Schubert discussed the value of microscopical examination of the cuttings from a number of German wells.

Although west coast paleontologists have modestly refrained from making claims, apparently the first well cuttings to be examined for Foraminifera in North America came from a bore hole in Santa Clara County, California. Chapman (1900) has the following to say about his investigation.

In consideration of the value of Foraminifera as indices of the relative age of a fossiliferous deposit, not so much with regard to isolated species, but with the general faunal aspect of the group, the present collection affords many points of interest.

Presuming the conditions of life and surroundings to be equal, we may fairly expect to find foraminiferal assemblages in many different areas of the earth's superficial deposits very closely related as to their percentage of species in common, provided they are comparable with one another, either homotaxially . . . or chronologically. On the other hand, we rarely find foraminiferal assemblages from deposits of decidedly different ages with a high percentage of species in common.

In March, 1897, I was favored by Dr. J. C. Merriam . . . with a sample of Tertiary marl from California, accompanied by a request that I would investigate the rock for its Foraminifera. . . .

The second samples [received] bear the label "from a well in Santa Clara Co." The rock is . . . crowded with Foraminifera, . . .

Thus it is apparent that prior to the last quarter-century microfossils were employed in a few isolated instances to establish the ages of strata penetrated by the drill. Surprisingly enough, the earliest microstratigraphic studies, therefore, inclined to be dominantly micropaleontological rather than microlithological.

One of the pioneer students of microstratigraphy was J. A. Udden (1914) whose work was especially important because through it he was able to serve as a catalyst to spur other geologists into action on similar researches. Udden made microscopic examinations in 1908 to 1911 of cuttings from wells drilled for oil or water in Illinois, and he also re-examined a few old cuttings from the Monmouth city well, Warren County, which was begun in 1887. Worthen had earlier (1890) published a record of this well based on sample examinations made by Professor J. H. Southwell. This was perhaps the earliest *American* detailed microlithologic investigation, though Southwell's work was slightly later than that of Professor Judd and associates.

Udden was the first to give a detailed outline of procedure in well-cutting examination. He also emphasized the microlithological characteristics of the rocks, mentioned a few of their micropaleontological features, and stressed the importance of well cuttings generally. Inasmuch as his paper, written a generation ago, is too seldom cited, it it may be pertinent to quote a few of his rather modern viewpoints. Udden stated:

If samples are not taken while wells are being drilled, the opportunity for collecting them is lost forever. . . . A few old well samples have been kept for many years, and it proved quite profitable to re-examine some of them. The record of the Monmouth well . . . is one of these. Devonian shale and limestone 109 feet thick and Kinderhook shale 124 feet thick were reported from

this well without any descriptive particulars. On re-examination of the shales in these samples, which have been preserved for twenty-five years, they were found to contain *Sporangites huronense*, which undoubtedly correlates them with the Sweetland Creek shale in Iowa . . . . It is evidently much more desirable to know the biological or physical characteristics of a shale or other rock, than to know that a shale or limestone exists at a given depth.

That Dr. Udden was this early interested in the utilitarian aspects of micropaleontology is clearly indicated by the following quotations.

In limestones as well as in shales it is always desirable to look for fossils. The experience of the writer has been that for this purpose it is necessary to dry the samples after washing and then to separate the smaller fragments from the larger ones by means of a set of sieves. . . . Fossils, such as impressions of leaves, thin shells of molluscs, shells of foraminifera, and spores of plants, will often be found in shales upon splitting the larger fragments with a knife. . . .

. . . Some specimens need to be submitted to specialists, and should be preserved for all time. Samples of this kind may be donated to some large museum. . . .

That Udden was cognizant of the utility of various kinds of microfossils is further indicated by his following statements.

The limestone above coal No. 6 is a remarkably persistent feature in the "Coal Measures." . . . In the wells which penetrate this limestone in the southern part of the State, it was possible to identify the rock in one-half of the number by the presence of fragments of *Fusulina cylindrica*. . . . It is believed that this fossil has a vertical distribution of less than 20 feet in the entire section of the "Coal Measures" in Illinois. . . . Associated with this *Fusulina* are almost always to be found fragments of *Rhombopora lepidodendroides*, some peculiarly tuberculated pinnules of a crinoid, and sometimes entire shells of *Endothyra*.

In the upper "Coal Measures" . . . some of the dark and grey shales contain shells of an *Ammodiscus*. . . .

Dr. Udden later continued his microstratigraphic work in Texas and published one of the pioneer papers (1921) on well cuttings from that state. According to Professor F. B. Plummer, Dr. Udden not only introduced micropaleontology into Texas from Illinois but he gradually sold the idea of its importance to oil-field geologists. At least as early as 1918 he had trained in his laboratory at Austin Mr. Wallace Bostick, who was then employed by the Rio Bravo Oil Company in Houston. Later Mr. Bostick gradually expanded the work in the Rio Bravo office, and E. T. Dumble, who apparently had recognized the potential value of microstratigraphy as early as 1913, engaged Miss Esther Richards, now Mrs. Paul L. Applin, to carry on the work which Bostick began.

Despite the developments just described, and others to be mentioned later, and in spite of the fact that as early as 1919 C. R. Eckes used microscopical examination of well cuttings to interpret logs of the Texas Duffer wells, *applied* micropaleontology really did not get well started in the Texas Gulf Coast until 1920 when Alva C. Ellisor, Hedwig T. Kniker, and Miss Richards began their studies of Foraminifera.

Miss Ellisor started to work for the Humble in Cisco, Texas, in late 1918 or early 1919. At that time she examined well cuttings from Permian and Pennsylvanian strata and worked on samples from Stratton Ridge salt dome, Brazoria County. Miss Ellisor left Cisco sometime in late 1919, or early 1920, but in the fall of 1920 rejoined the Humble Company, this time in Houston. Her new job was to make microscopic examinations of well cuttings, to test for shows of oil and for chlorine content. At first the deepest wells drilled were carried to about 3,000 feet, and did not go below the non-marine beds of the Miocene. In a short time, however, the Humble drilled below 3,000 feet at Goose Creek. In washing the samples from these wells, Miss Ellisor discovered Foraminifera. Not having the necessary literature at hand, she asked Mr. Wallace Pratt to send the fossils to Dr. Cushman for identification, and he did so. Inasmuch as every new discovery was kept very confidential in those days, neither Miss Richards nor Mr. Dumble at first knew about the fossils. Finally, however, Mr. Pratt informed John Suman, who at that time was with the Rio Bravo, and his company was then given samples from the Humble wells. In 1921, Mr. Dumble wrote a paper on this subject entitled, "Recent Geological Work in the Gulf Coast Oil Fields," and Miss Richards read it before the G.S.A. meeting at Amherst, in December of that year.

Miss Ellisor states that, "The Humble was the first to discover the presence of foraminifera in the Gulf Coast of Texas and to make a study and application of them.* When I first came to Houston, I called on Mr. Dumble and he told me that a Miss Richards had just come to work for him, but was at that time in Florida collecting macro-fossils. At the time of my visit with Mr. Dumble, he made the statement that there were no foraminifera in the Gulf Coast of Texas, but there were some small macro-fossils such as in the Stratton Ridge wells and 'Galveston deep well.' For that reason, he had sent Miss

* Udden (American Jour. Sci., Vol. 40, pp. 151-156) as early as 1915 had, however, called attention to the occurrence of Cretaceous Foraminifera from a well in Culberson County, the identifications having been made by Professor Cushman.

Richards to make a collection of the Florida Miocene fossils for comparison."

Miss Kniker joined Dr. Udden's laboratory, in June, 1920, at a time when samples from Cretaceous wells in central Texas as well as some cuttings from the Midway, Wilcox and Claiborne, had already started to come in. At this time E. B. Stiles, who through some oversight has ordinarily not been mentioned among the pioneers, also was actively engaged in micropaleontological and microlithological studies under Dr. Udden's guidance. In addition, Sam Aronson was being trained by Dr. Udden and was employed in Dallas as early as 1921 by the Atlantic Refining Company to do paleontological well-sample work. Dr. Udden had hired Stiles when V. V. Waite, who examined well samples for Dr. Udden for several years prior to 1920, left to go into commercial work at Dallas. Udden and Waite, prior to the summer of 1920, had issued a limited private edition (mimeographed and illustrated with actual photographs) of "Microscopic Characteristics of the Bend and Ellenburger Limestones." This was an excellent paper, especially for those early days, and the article appeared in print in 1927 as University of Texas Bulletin 2703. Mr. Stiles and Miss Kniker also made up a collection of several volumes on Paleozoic Foraminifera for use in identifying specimens found in well samples. Although Dr. Udden's specialty was lithologic characteristics, and his assistants were taught to take advantage of all lithological peculiarities possible, he carefully checked all these foraminiferal descriptions.

It has become traditional that Mrs. Applin, Miss Ellisor and Miss Kniker are regarded as among the earliest pioneers in the micropaleontology of the Gulf Coast. But there will probably always be some question as to whether or not the Humble laboratory in Houston was established as early as that of the Rio Bravo Company. Inasmuch as Humble (and probably Roxana) operated a laboratory in north-central Texas prior to opening the one in Houston, both the Humble and the Rio Bravo deserve especial credit for their pioneering spirit. In those early years Dumble naturally, and with considerable justice, was fond of saying, "These results were obtained by methods originated in the laboratory of the Rio Bravo Oil Company." But Mr. Wallace Pratt might well have said, "We were there, too." It has also generally been taken for granted that commercial paleontology was started in Houston, but the Atlantic Company, operating in Dallas, certainly was not far behind.

Although it might be said that applied micropaleontology did not

get started generally on the Gulf Coast until autumn, 1920, it was well established in Dr. Udden's laboratory at least as early as the summer of the same year, for Miss Kniker states that when she arrived at Dr. Udden's laboratory, he and Mr. Stiles were already identifying the more common foraminiferal assemblages they discovered in their work without much trouble.

Whatever is eventually decided in these relatively unimportant priority matters, most micropaleontologists will agree with Miss Kniker when she says, "One fact that has always impressed me is that in those early years Dr. Udden trained several micropaleontologists, one after another, and then sent them out to work for oil companies, thus furnishing trained personnel for the work he considered of prime importance. He realized his laboratory could not begin to look at all the samples that should be worked, so this was a happy solution. This was mostly in the days before universities trained micropaleontologists."

In order properly to continue a story which now begins to have many ramifications, it is necessary to take up the significant contributions which Professor J. A. Cushman has made both to the academic and the utilitarian phases of micropaleontology. In 1914, the same year that Udden's notable Illinois Survey paper was issued, L. W. Stephenson (1914) described the geology of a deep well at Charleston, South Carolina. The cuttings from this well had been examined by Cushman. Inasmuch as this is the first instance of a *detailed* micropaleontological analysis of strata penetrated in a well, some sections of Dr. Cushman's report are briefly quoted.

> The Foraminifera of the deep well at Charleston have been examined carefully down to station 50 (depth 920 feet), where the known Cretaceous begins, in order to determine, if possible, the limits of the Cretaceous in the questionable sections above. The samples of the Cooper marl . . . contain a very rich foraminiferal fauna, as will be seen by the accompanying chart of distribution. . . . In general it is such an assemblage as may have occurred in water ranging in depth from 100 to 200 fathoms. It is most marked by the practical absence of the Miliolidae, only one species being present and that allied to the forms found in the deeper water of present oceans.
>
> A study of the washed material from stations 25 to 50, the questionable section, soon showed that material from several horizons had been mixed. As noted by those who had previously examined the lithology of this material, the Cooper marl had dropped down in the boring and had been mixed nearly throughout the samples taken below, so that it became necessary to eliminate the Cooper marl species from each sample. . . .
>
> It became apparent that the upper part of the section was of slight interest as far as the Foraminifera were concerned . . . but when sample 43 was reached a marked change was shown in both the physical character of the test and in the species. At this level there were specimens of the genus Vitre-

webbina attached to specimens of Cristellaria and Nodosaria. This genus is recorded from the Cretaceous of New Jersey by Bagg. These and certain other forms occurring at this level seem to show that the Cretaceous strata here lie as high as the 750-foot level. The same species characterize the samples taken immediately below.

Many of the forms, especially those of the Cooper marl, have been referred to known species, but the whole series shows marked differences from allied known faunas and the material must be carefully studied in conjunction with that from other localities for final determination. . . .

Although the exact date can no longer be ascertained, the results of the micropaleontological work on the Charleston well soon thereafter led the United States Geological Survey to send Dr. Cushman samples from oil wells for age determinations. Now, at long last, micropaleontology, which had had such a protracted period of birth and such a difficult and uncertain infancy, was, from this time on, to grow by leaps and bounds.

ACADEMIC BACKGROUND OF MICROPALEONTOLOGY

Unfettered, unhampered, occasionally undirected—yes, even apparently aimless—academic research commonly results in commercial applications of far-reaching economic importance. A brief examination of the scientific backgrounds of Professors J. A. Cushman and J. J. Galloway will serve particularly well to illustrate this point. Other examples are, of course, available but space limitations prevent their citation.

Dr. Cushman's earlier work was purely from the scientific point of view. He became interested in the Foraminifera in 1901 through reading Dr. J. M. Flint's (1899) report on the Albatross Foraminifera and H. B. Brady's (1884) Challenger monograph. He then worked on the Foraminifera as a basis for his S.B. thesis under the direction of Dr. R. T. Jackson at Harvard University in 1902–1903. In 1904–1905 he studied the living forms at the United States Bureau of Fisheries Laboratory at Woods Hole, whereupon the United States National Museum asked him to take up the study of their foraminiferal material. Proceeding to Washington, he met and was stimulated by Dr. Flint, and found that the United States Geological Survey wanted him to work on the fossil representatives of the group.

Feeling that he must know the living forms better, Dr. Cushman first studied Pacific species. A little later he agreed to investigate for the Survey, in order, Pleistocene, Pliocene, and Miocene species, believing that only in this way could their ranges be worked out satisfactorily. Results later proved that this was a sound approach to the problem. Soon it became apparent to Dr. Cushman that the very long

range of many species, given as "Cambrian to Recent" in published statements, was erroneous, and had to be corrected. At first he was roundly criticized for "splitting" forms into numerous species, but later *the commercial* applications abundantly proved the general validity of his course of attack on a problem which was, at the time, totally non-utilitarian.

Moreover, it was largely on the basis of this "species splitting" that there was built up the possibility of the use of Foraminifera as *detailed* index fossils. The general theoretical background was being slowly worked out in the decade before 1914 when, at last, its applicability in the analysis of the cuttings from the Charleston well was cited in print.

Professor Galloway commenced studying paleontology under Professor E. R. Cumings of the University of Indiana in the fall of 1906. One of his first problems was the identification of a large Waldron fauna in which work it was necessary to use the microscope in identifying bryozoans, ostracodes, and the young stages of brachiopods. He also studied the Salem microfossils, and then investigaged Ordovician Bryozoa for a six-year period from 1909 to 1916. Joining the staff of Columbia University in 1916, he spent a year in classifying Bryozoa in the American Museum of Natural History. By this time, although he had not consciously directed his studies toward that end, he was a well trained general micropaleontologist, but without much experience with the Foraminifera.

In the fall of 1917 Dr. Galloway received from the Mexican Importing and Exporting Company, through Dr. C. P. Berkey, 120 bags of cuttings from a well the location of which he did not know. He was asked to ascertain "if the geological formations, as indicated by the samples, correspond to those which are usually found in the vicinity of oil-well fields, and would warrant further exploration from an economical standpoint." He identified and determined the ranges and abundance of all the microfossils, including 65 species of Bryozoa, Pelecypoda, Gastropoda, Ostracoda, and others, and 45 species of Foraminifera. The Foraminifera, which were by far the most abundant, seemed to be the most useful. The beauty of the Foraminifera and a desire to rectify their nomenclature led Dr. Galloway to study them from that time on. He finished his elaborate report on the well, which turned out to be in Yucatan, in February, 1918.

Through one of his students, Mr. E. W. Ames, Dr. Galloway was employed in 1919 by the Pierce Oil Corporation to try to correlate the formations in wells in the Ranger district of Texas. His laboratory was in the back end of a bank building in Cisco, Texas. At the time he

found it difficult to use microfossils for correlations in that area, first because the fossils had to be picked out and identified with almost no literature, and little or no equipment, and secondly, because the formations had not been named and described. Thus his work continued, but with only moderate success, until the fall of 1920.

In 1920 he studied cuttings from a well drilled by the Standard Oil Company at Chipley, Florida, and determined the contacts of the Tertiary and Cretaceous formations down to the Tuscaloosa. This he did largely by means of Foraminifera, using European Cretaceous literature for identification.

In the fall of 1922 Dr. Galloway received from the then chief geologist of the International Petroleum Company of Mexico, Mr. E. A. McKanna, a large amount of surface fossils and rock from Mexico, as a basis for the determination of the ages of the rocks, and the identification of the fossils, preparatory to the recognition of horizons in wells. In the summer of 1923 he was employed, by the same company, to go to Tampico to work on the micropaleontology of the oil fields of Mexico; and he set up one of the early laboratories for International Petroleum at that time.

From these short surveys it will be seen that Drs. Cushman and Galloway both went through a period of "cloistered" research before applying the knowledge thus gained to commercial problems. Their *teaching* of the subject of micropaleontology, however, appears to have resulted in large part from stimuli encountered in their utilitarian experiences. But micropaleontology as a part of the collegiate curriculum is discussed under another heading.

ACADEMIC AND COMMERCIAL BACKGROUNDS OF MICROPALEONTOLOGY ON THE WEST COAST

Turning now to the West Coast we find that microstratigraphic research apparently began in California as early as 1919. By early 1925 laboratories had been established by seven of the largest oil companies, with 23 people engaged in the work, and both Stanford University and the University of California had taken academic cognizance of the new field of micropaleontology.

Credit for the discovery that the microfossils could be used for correlation of sediments in California probably belongs to E. Call Brown, of the California Petroleum Corporation, who, during October, 1919, studied them in cuttings from the Huntington Beach field.

Dr. J. P. Smith, professor of paleontology of Stanford University, early appreciated the significance of this sort of investigation and in the fall of 1921 F. G. Tickell, working under a grant from several of

the California oil companies, began his studies under Dr. Smith's direction at Stanford. Research was continued at the California Academy of Sciences from 1922 to May, 1923, when J. A. Taff and E. G. Gaylord, of the Pacific and Associated Oil companies, became convinced that the results were sufficiently encouraging to warrant more extensive investigations.

In June, 1921, the Pacific Gas and Electric Company began the drilling of a deep test well about 20 miles east of Suisum, California. The geological work was under the direction of Professor Bailey Willis of Stanford University. Professor Willis, although a structural geologist, was keenly aware of the value (if not the name) of micropaleontology, and he arranged to have three former graduates in geology stationed at the well to carry out extensive microscopical studies on the sediments encountered. Those so employed were Ralph Copley, David Anderson and Thomas Radcliffe (replaced by Thomas F. Stipp).

The following list, as of January 1, 1926, gives the names of those California institutions and companies with the employees who were pursuing microscopic work almost exclusively.

Stanford University—Hubert G. Schenck and F. G. Tickell

Associated Oil Company—work begun in May, 1923; G. Dallas Hanna and T. F. Stipp

California Petroleum Corporation—work begun in October, 1919; E. Call Brown and one assistant

Maryland Oil Company of California—work begun in summer of 1923; R. D. Reed, Donald D. Hughes, James P. Bailey, J. M. Hamill, and C. C. Church

Milham Exploration Company—work begun in June, 1924; George H. Doane, and Paul P. Goudkoff

Shell Oil Company—work begun in 1923; Guy E. Miller, John D. Gilboe, Eros M. Savage, and Miss Dosca W. E. Monical

Standard Oil Company of California—work begun in February, 1925; H. L. Driver, Frank Tolman, G. R. Elliott, Victor Davenport, Harold M. Horton, and E. C. Meek

Union Oil Company of California—work begun January 1, 1925; Stanley G. Wissler and one assistant

By 1940, according to Schenck (1940), 17 *commercial* micropaleontological laboratories had been established in California and only 3 abandoned. The 14 active laboratories employed a total staff of about 100, most of whom could legitimately be called micropaleontologists. Interestingly enough, only 3 of the laboratory chiefs have had what might be called formal training in micropaleontology. This, however, is not surprising when it is remembered that most of the men involved are pioneers whose training period antedates the academic beginnings of the subject. Altogether the California laboratories handle more than 100,000 samples per year, and doubtless have an annual operating expense of not far from one-half million dollars.

MICROSTRATIGRAPHY AND WELL CUTTINGS

It is obvious that today, as in the past, advances in commercial microstratigraphy are dependent on the ready availability of well cuttings. Owing to the foresightedness of a few men such as Dr. Udden, sampling of cable-tool wells became less and less uncommon beginning about a quarter-century ago. Moreover, to its great credit, the United States Geological Survey at least as early as 1904 had made standard the plotting of well logs using graphic strips on the scale of 100 feet to the inch.

It is a matter of common knowledge that rotary drilling first came into general use in 1901 with the development of the Spindletop field, Jefferson County, Texas. Similarly, most persons are aware that today probably three-fourths of the wells from which samples are examined are drilled with rotary tools. Consequently, at present one of the first procedures the commercial micropaleontologist is taught is to determine which of the microfossils in a rotary sample actually are indigenous to the strata penetrated in the interval sampled. But in the early development of rotary drilling, the samples were considered nearly, if not quite, worthless. Whiteside (1932) has stated:

> C. W. Tomlinson, . . . while working in the Graham field in Carter County, Oklahoma, in 1922, made attempts to obtain cuttings at each 5 to 20-foot interval, by catching the return mud in buckets at the end of the trough over the settling pit. These samples were washed, screened, and presumably arranged at the well in consecutive order for examination without the use of a microscope. Tomlinson, to our knowlege, is among the first who made attempts to obtain rotary cuttings samples in an orderly manner.
>
> Few (if any) systematic sets of cuttings were consistently preserved for comparative reference until 1925, when several companies began the practice with the development of the Hubbard or Retta field in Kay County, Oklahoma.

Thus it is apparent that, despite pioneer papers by Trager (1920), Aurin, Clark, and Trager (1921), Udden (1921), Kraus (1924) and others, rotary-well cuttings were not *consistently* taken, preserved, and studied until about 1925. But, as we have seen, by 1926 several companies operating in the Texas Gulf Coast and in California had already achieved considerable success with applied micropaleontology. Peculiarly enough, even at this relatively late date, micromineralogy was still lagging far behind micropaleontology.

Powers (1926) succinctly summarized the status of microstratigraphy at this time as follows.

> Micropaleontology became an integral part of the oil business in 1924. . . . Lithology and heavy minerals are also used in coordination with fossil evi-

dence. This work has brought about a reorganization of scouting activities. . . . In 1926 samples were being collected from practically every wildcat well in Oklahoma, Kansas, and Texas . . . some companies have even taken microscopes on the derrick floors to interest the drillers in making accurate well logs. As the search for oil becomes more intensive the systems for finding and recovering oil become more elaborate.

SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS AND ITS JOURNALS

We have now examined some phases of the history of micropaleontology during its adolescent period. The time is late March, 1926, and the American Association of Petroleum Geologists is in session at Dallas, Texas. On this occasion Mr. and Mrs. F. B. Plummer, and others, arranged for a dinner meeting of a score of persons especially interested in paleontologic and stratigraphic research. Those who participated were practically all academicians. After attaching such a stigma, perhaps some would counsel against listing their names as follows.

Mr. and Mrs. F. B. Plummer
Dr. Raymond C. Moore
Dr. David White
Dr. Lloyd W. Stephenson
Dr. Henry V. Howe
Dr. and Mrs. W. M. Winton
Mr. and Mrs. F. L. Whitney
Miss Grace Newman
Dr. and Mrs. Charles Schuchert
Mr. and Mrs. Paul Applin
Professor J. J. Galloway
Dr. and Mrs. Charles E. Decker
Professor Junius Henderson
Professor E. B. Branson

An organization committee was immediately formed consisting of

Chairman, F. B. Plummer, Fort Worth, Texas
Mrs. Paul Applin, Forth Worth, Texas
Donald D. Hughes, Los Angeles, California
Raymond C. Moore, Lawrence, Kansas
F. L. Whitney, Austin, Texas

The committee revealed its purposes to the executive committee of the American Association of Petroleum Geologists, which gave general approval, to form a paleontological society and make plans for a quarterly journal of micropaleontology. No scientific subject really attains maturity or recognized standing until it is of sufficient importance for its protagonists to found a society and to support a journal. Through the committee action just mentioned micropaleontology as a subject grew up literally over night.

At the Tulsa meeting of the American Association of Petroleum Geologists, in March, 1927, Dr. Henry V. Howe, of Louisiana State University, was selected as temporary chairman, the present name of the society was selected, and a publication, to be known as the *Journal of Paleontology*, was authorized. The society, whose birthday is offi-

cially stated as March 25, 1927, began its existence with 80 charter members. The first officers were:

President, J. J. Galloway, New York City, New York
Vice-president, Donald D. Hughes, Los Angeles, California
Secretary-treasurer, Marcus A. Hanna, Houston, Texas
Editor, Joseph A. Cushman, Sharon, Massachusetts

Work started immediately on the *Journal*, Volume 1 of which appeared in July, 1927. From this time to the present the annals of micropaleontology are written largely, but of course far from entirely, in the pages of the *Journal of Paleontology;* and the progress of the field has proceeded hand in hand with the growth of the sponsoring society, the salient features of whose history were recently reviewed (1940) by past-president R. C. Moore, who has given distinguished service to the Society as founder, officer, and editor.

Some measure of the instantaneous success and general acceptance of the *Journal of Paleontology* may be judged from the fact that papers have from the first been submitted for publication at a more rapid rate than they can be printed. Nevertheless the first eight volumes contained 3,325 pages, 344 plates, many text figures, charts, and maps. In addition to reviews, memorials, and the like, the articles printed can be classified roughly as follows.

	Papers		*Papers*
Foraminifera	77	Conodonts	7
Ostracoda	37	Sedimentation	5
Mollusca	20	Brachiopoda	4
Technique	15	Miscellaneous groups	22
Diatoms	10	General	41
Cephalopoda	9		

As numerous papers on the subject of sedimentation began to be submitted, it seemed wise to establish a separate journal for their inclusion. Finally, the first number of the *Journal of Sedimentary Petrology*, the second official publication of the Society, appeared in May, 1931.

Soon the Society of Economic Paleontologists and Mineralogists was faced with another problem. Publishing the number and the variety of papers that were submitted not only taxed the finances of the Society but exceeded the original scope of the *Journal.* Inasmuch as many of the papers were submitted by members of the Paleontological Society of America, which never had had a separate publication of its own, and because many of the members of that society also belong to the Society of Economic Paleontologists and Mineralogists, the publication problem was freely discussed, and solved, by the councils of the two societies. As a result, beginning with Volume 9, 1935, the *Journal of Paleontology* became a joint publication of the Society

of Economic Paleontologists and Mineralogists and the Paleontological Society of America.

As a consequence of this important scientific merger, the last six volumes of the *Journal of Paleontology*, 1935 to 1940 inclusive, were considerably enlarged, containing altogether 4,120 pages and 485 plates, in addition to many text figures, charts and maps. The papers also cover a somewhat broader range of topics, as shown by the following rough catalog.

	Papers		*Papers*
Foraminifera	61	Conodonts	9
Mollusca	40	Insecta	8
Cephalopoda	37	Reptilia	8
Ostracoda	32	Sponges	7
Trilobita	29	Asteroidea	6
Mammalia	19	Paleoecology	5
Corals	18	Graptolites	5
Brachiopoda	15	Paleobotany	5
Technique	12	Miscellaneous groups	30
Crinoidea	11	General	37

Although the Foraminifera, based on the number of papers published concerning them, continue to be the most important micropaleontologic group by a wide margin, other groups are constantly receiving more and more attention. Moreover, the significance of any one group of microfossils obviously can not be judged solely on the basis of the amount of space devoted to it in the current journals. This point is well demonstrated by the results of Schenck's (1940) graphic analysis of the statements in 100 replies to a questionnaire he sent to 166 micropaleontologists working in many different areas on cuttings from rocks of the several different fossiliferous systems. The rating of the principal categories of microfossils was not vastly different from that suggested by the number of papers devoted to the same groups in the *Journal*. That is, first place was held by the Foraminifera, second by the Ostracoda, and third by the Mollusca. Fourth place, however, was allotted the Bryozoa, a group which *Journal* authors, at least, have consistently avoided, and other little publicized groups were recognized as having considerable potential future significance.

Professor Herbert L. Hawkins in his recent Alexander Pedler lecture (1939) at Worthington, England, whimsically observed,

> The character and evolution of extinct micro-organisms seems a topic that can serve little useful purpose save to keep some crank out of worse mischief. . . . Nevertheless, petroleum companies find it advantageous to employ experts on the evolution of foraminifera.

Merely on the basis of the number of micropaleontological papers

published in the *Journal of Paleontology* not a few cranks—perhaps we had better say "members of the profession"—are indeed kept out of mischief. But the great bulk of micropaleontological investigation and research fails to be recorded in the public journals. This work is done by those very experts the "petroleum companies find it advantageous to employ."

At present there are probably 500 persons definitely engaged in some sort of micropaleontologic, or at least microstratigraphic work, and many other persons are somewhat more tenuously connected with the field. The total annual appropriation to support their activities must be well in excess of $2,500,000. According to one estimate, oil companies in the Gulf Coast region may even spend sums ranging from $1,000 to $2,500 to acquire detailed micropaleontological information on a single wildcat well. Truly micropaleontology has come up in the world during the past quarter-century!

We have now examined at some length the commercial development of the field, and have seen something of the significant rôles "academic" or "cloistered" scientists played in its establishment. Let us next study the rise of micropaleontology as a subject in geological curricula, and see how, in turn, and rather paradoxically, its university growth was in considerable part dependent on its expanding utilitarian usage.

RISE OF MICROPALEONTOLOGY AS A SUBJECT IN GEOLOGICAL CURRICULA

It is extremely difficult to determine just when micropaleontology had its beginning as a subject for instruction in American university departments of geology, for more or less inadvertently some elements of the subject have been taught for many years. For example, to cite only one of doubtless many instances, Professor E. R. Cumings, of the University of Indiana, has been training students to work on certain groups of microfossils for over forty years. But in the sense of real continuity of presentation and unity of course context the subject has just reached its majority.

For several years prior to 1920 the course called "Principles of Paleontology" at Columbia University involved the generalized study of several different groups of invertebrates followed by a detailed generic, specific, and ecological investigation of a single group. A different group was chosen each year for this detailed study, and doubtless because of Dr. Galloway's awakened interest in the Foraminifera as a result of his experience with them in the cuttings from the well in Yucatan, that group was selected for study during the

spring of 1920. In 1921 the Foraminifera again were studied as the major part of the course. This continuity of major subject matter in a course which previously had featured a yearly change in the zoölogical group emphasized was not surprising. As early as 1919 Dr. H. N. Coryell, also of the Columbia University department of geology, had written a commercial report based on microfossils from some Cuban samples, and he introduced the study of microfossils to the laboratories of the Pure Oil Company in Tulsa, Oklahoma, during the summer of 1922. Thus early, micropaleontology had two protagonists at Columbia rather than one, and through them the real impact of the petroleum industry on the paleontological curriculum was about to be felt.

In the fall of 1923, as Dr. Galloway "realized that micropaleontology was an indispensable part of petroleum geology, *and an additional outlet for students of geology*," he organized his first formal class in Micropaleontology, with the following students enrolled: Sam Aronson, George H. Doane, Corbin D. Fletcher, and Stanley Wissler. All but Fletcher, who is deceased, are still micropaleontologists. In the fall of 1924 the course in micropaleontology was entered in the Columbia University catalog, as previously cited, with 13 students enrolled, including the following, who are still active as micropaleontologists for oil companies: Frances Charlton, John Cruse, James B. Dorr, S. W. Lowman, K. C. Stewart, R. E. Stewart, N. L. Thomas. According to Dr. Galloway, in this early course he

> treated small fossils just the same as large fossils, identified them and determined their ranges, looked for index fossils, and for common associations by which horizons can be recognized, just as paleontologists have always done, and as petroleum micropaleontologists still do.

Glenn D. Hawkins used part of the Mexican material sent to Dr. Galloway in 1922 by the International Petroleum Corporation for his master's thesis, entitled "Foraminifera from Southern Mexico." Hawkins was thus one of the very first students specifically trained as a micropaleontologist, and his is one of the early American theses devoted exclusively to fossil Foraminifera.[4]

The first Columbia University students to achieve doctorates in micropaleontology under Dr. Galloway were Dr. M. P. White, who took his degree in 1929, and Dr. A. S. Warthin, who was graduated in 1930.

During the middle twenties a restudy and revision of the Foramin-

[4] Dr. J. A. Cushman's S.B. Thesis on Foraminifera was, of course, written a generation earlier.

ifera resulted in a preliminary copy of Professor Galloway's manual, with photographic copies of the genotypes and mimeographed copies of "family trees," all of which were used for instructional purposes. In 1927 lectures given by Dr. Coryell introduced the ostracodes formally into the realm of micropaleontological class work at Columbia where since 1930 their study has formed the basis of a full semester course.

Dr. Hubert G. Schenck began teaching micropaleontology formally at Leland Stanford Jr. University in the autumn of 1924, but as early as 1923, while teaching at the University of California, he directed the study of Foraminifera carried on by several students, who later became well known economic micropaleontologists.

Dr. Schenck's interest in microfossils was aroused when he was geologic assistant in the Bureau of Mines, Manila, Philippine Islands, in 1920–21. There he saw the potential value of Foraminifera to the stratigrapher. When he joined the Stanford staff in 1924, he found several graduate students interested in the application of microfossils to oil-field work. In addition, he discovered an excellent thesis entitled "Microscopic Methods in the Correlation of Oil-Field Sediments," written by Donald D. Hughes for the degree of engineer of mines in the department of mining and metallurgy, and dated March, 1924. Hughes had been working on microfossils at the same time Ralph D. Reed was completing his thesis on heavy minerals for the doctor's degree. A few other graduate students had also carried on some work on microscopic fossils under the direction of Professor J. P. Smith, as previously mentioned. Thus, when Professor Smith, in 1924, suggested that Dr. Schenck organize a micropaleontological laboratory, some of the groundwork had already been accomplished. There remained, however, the real problem of getting a laboratory constructed and a class under way.

In organizing the laboratory, Schenck states that

> I was influenced considerably by Dr. G. Dallas Hanna, whom I consulted frequently. The instruction I gave was designed to train students for oil field work—that was the reason for organizing the laboratory in the first place. The procedures we followed were those already in use in oil companies, insofar as our limited funds permitted. Throughout the early days of our laboratory I also benefited from the suggestions of Dr. Reed, Mr. Hughes, H. L. Driver, and many others in the oil business.

Recognizing the need for a publication medium in micropalentology, Professor Schenck early in 1926 founded the *Micropaleontology Bulletin* which, according to a notice carried on the cover of a reprint of Volume 1,

was established in March, 1926, to further the knowledge of the smaller fossils, especially on the West Coast of North America, but also of other parts of the world where such knowledge has a bearing on micropaleontology as a whole.

The *Bulletin* was issued tri-annually for several years, but as the *Journal of Paleontology* became well established there was less and less need for this West Coast publication, and it was finally discontinued.

Turning our attention to the east again, we find that while Columbia and Stanford were getting their work in micropaleontology inaugurated, Professor Cushman had founded the Cushman Laboratory for Foraminiferal Research at Sharon, Massachusetts. From the first he accepted a few special students, many of whom have subsequently become leaders in the field. In April, 1925, he issued Volume 1, Number 1, of the *Contributions from the Cushman Laboratory,* as the first regular micropaleontology journal. By the following year Harvard University had made an arrangement with Professor Cushman whereby he became lecturer in micropaleontology on the staff of the department of geology. From that time on Harvard graduate students were able to take up residence work for extended periods under his direction in his laboratory at Sharon.

The history of the development of micropaleontologic instruction at any one of several other institutions would read somewhat the same. For instance, although all the facts are not at hand, Professor F. L. Whitney, of the University of Texas department of geology, apparently influenced by the success of the Rio Bravo and Humble micropaleontologic laboratories, established micropaleontology as a course and listed it in the 1923-24 University catalog. Professor Whitney and his assistant, Dorothy Carsey, therefore, gave the earliest *regularly announced* University course in the subject.

Realizing that many courses are offered, or abandoned, without catalog statement to that effect, a fairly accurate idea of the growth of micropaleontology may none the less be obtained by an examination of University and College catalogs for the past score of years. The results of such an investigation show that from 1923–24, when both Columbia and Texas first offered courses in micropaleontology, to 1940–41, when Tulane added the subject to its curriculum, at least thirty-one institutions have given regular instruction in the field. Therefore we may judge that educationally the subject is now more significant, say, than the art of tumbling, and that instruction in it is only slightly less important than pedagogy in cosmetics—which, of course, is very important indeed.

Fig. 10.—Professor J. A. Cushman in the Cushman Laboratory for Foraminiferal Research, Sharon, Massachusetts.

Although the detailed figures are not available, it is probable that a considerable proportion of the students to-day listed as trained in paleontology have actually had considerable grounding in some phase of micropaleontology. Of the approximately 40 persons who have at least completed their residence work for the doctorate in paleontology or stratigraphic paleontology at the University of Chicago in the past

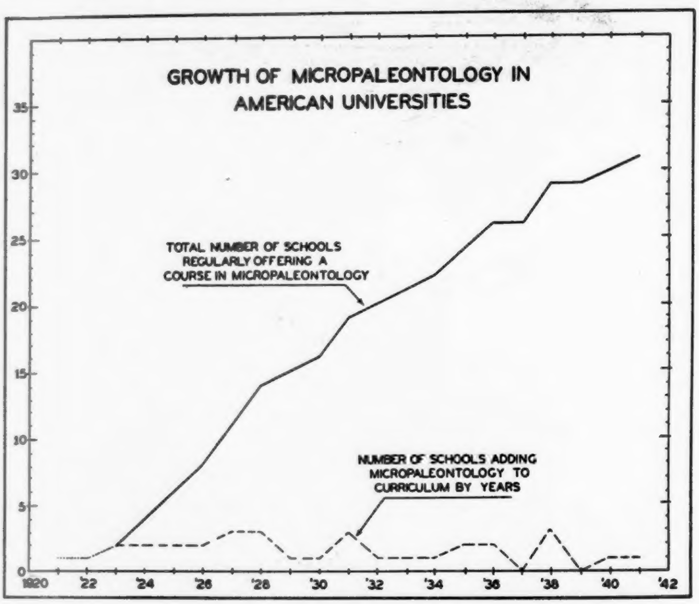

FIG. 11.—Graph showing growth of micropaleontology in curricula of American institutions from 1921 to 1941.

13 years, all but seven have taken work in micropaleontology, and 14 have specialized in some aspect of that field. In addition, eight of the last 14 master's degrees awarded in invertebrate paleontology were based on micropaleontologic studies. Doubtless the records of most large departments would show at least a somewhat similar trend.

If, in addition, it is remembered that most macropaleontologic investigations must now employ microscopic techniques, it will be seen that nearly all paleontology is to-day a sort of micropaleontology.

ORGANIZATION AND ADMINISTRATION OF A COURSE IN MICROPALEONTOLOGY

For some years after micropaleontology had its academic inception it was customary for most teachers to use the Foraminifera almost

exclusively as the basis for study. Although this procedure was perfectly understandable, it might legitimately be compared with teaching the invertebrate paleontology of the Paleozoic on the basis of the ubiquitous brachiopods alone. A few teachers realized this weakness and gradually added other groups for study, commonly the ostracodes, the conodonts, and, more rarely, the bryozoans. But with rare exceptions most institutions still fail to stress a host of other groups that also have, or some day will have, micropaleontologic significance.

The well balanced course in micropaleontology should, the writer believes, follow some variant of the appended, incomplete, skeletal outline.

MICROPALEONTOLOGY

- I. Introduction
  - A. Definitions
  - B. General purposes of micropaleontology
    - 1. Academic
    - 2. Utilitarian
  - C. Statement of specific purposes and regulations of course
  - D. Historical development of subject
  - E. Preliminary survey of modern authors and literature
- II. Preliminary survey of the kinds of microfossils
  - A. Fossils of typically megascopic animals
    - 1. In dwarfed condition, represented by
      - a. Assemblages, such as the Salem fauna
      - b. Individual classes, such as
        - (1) Microscopic crinoids*
        - (2) Microscopic gastropods, and so forth
    - 2. In nepionic and neanic stages of development, such as
      - a. Embryonic echinoderms, especially
        - (1) Blastoids
        - (2) Crinoids
        - (3) Echinoids
      - b. Embryonic to youthful brachiopods
      - c. Embryonic to youthful pelecypods
      - d. Embryonic to youthful gastropods
      - e. Embryonic to youthful cephalopods
      - f. Protaspid trilobites, and so forth
    - 3. Represented by parts, fragments, or excrementa, such as
      - a. Sponge spicules
      - b. Coral sclerodermites
      - c. Echinoderm remains
        - (1) Pelmatozoan plates and ossicles, such as
          - (a) Crinoid columnals
          - (b) Pore rhomb cystoidean plates, and so forth
        - (2) Eleutherozoan plates, spicules, and so forth
          - (a) Ophiuroid vertebral ossicles, plates and spines
          - (b) Asteroid plates, and pedicellariae
          - (c) Echinoid plates, spines, pedicellariae and lantern parts, such as braces, pyramids, compasses, epiphyses, and teeth
          - (d) Holothurian spicules, plates, and faecal castings
      - d. Bryozoa, *usually* in fragments
      - e. "Vermes" remains, such as
        - (1) Setae
        - (2) Faecal castings
        - (3) Scolecodonts
      - f. Molluscan remains, such as
        - (1) Radulae
        - (2) Otoliths ?
        - (3) Opercula

g. Arthropod remains, such as
(1) Free cheeks, spines, pleural segments, and ventral plates of trilobites
(2) Barnacle plates
h. Fish parts, such as
(1) Dermal ossicles and scales
(2) Branchial structures
(3) Teeth
(4) Otoliths
B. Fossils of microscopic or near-microscopic animals
1. Protozoa
a. Foraminifera
(1) Calcareous
(2) Arenaceous; i.e., in insoluble residues
b. Radiolaria
c. Other protozoans ?
2. Ostracoda
3. Normally (undwarfed) relatively small invertebrates, for example
a. The smaller mollusca
b. Various worm tubes, and so forth
C. Fossils of microscopic or semi-microscopic plants
1. As entities, such as
a. Diatoms
b. Charophytes (may belong under C2)
c. Flagellates†
(1) Silicoflagellates
(2) Coccoliths
(3) Discoasterids
(4) Dinoflagellates, and so forth
2. In the form of fragments, such as
a. Spores and pollen
III. Methods of study
A. Collection of samples, from
1. Beaches
2. Sea bottom
3. Outcrops
4. Wells, in the form of
a. Cuttings resulting from various drilling procedures
b. Liquids, such as
(1) Oils
(2) Brines and waters
B. Procedures in separation of specimens
C. Procedures in mounting of specimens
D. Procedures in sectioning of specimens
E. Illustration for laboratory use or for publication by means of
1. Drawings
2. Photography
3. Combination of both
F. Procedures employed in commercial use of microfossils
IV. The zoölogical groups, listed under Division II, described in detail

* The term microscopic is of necessity used loosely in this paper. Many "microfossils" can be readily seen with naked eye, or studied under low magnifications.
† Exact biological position of some forms still uncertain.

Each instructor will naturally develop such a course differently according to his own individual background, experience, and ingenuity. Dr. Coryell at Columbia, for instance, now employs the following plan of instruction.

1. One lecture each week on historical phase, anatomy, structures, ecology, taxonomy, and distribution

2. One lecture each week on generic relationships and differential characters within a family group or groups
3. One laboratory each week on identified faunal groups dealing with genera and species
4. One laboratory each week based on an unknown surface sample to form the basis for a faunal, geological, and geographical report
5. Instruction in laboratory techniques for the preparation of surface and subsurface samples, methods of mounting, labelling, filing, and studying the specimens forms a more or less continuous assignment.

But whatever the pedagogical mechanics employed in conducting a class in micropaleontology, the *context* will always be of greatest importance. It seems to the writer imperative, therefore, not only that all, or at least most, of the micropaleontologic groups cited should be studied, but that the groups of microfossils which do not now have great utilitarian usage should receive a disproportionately large share of attention. Only by such a procedure will new groups gradually come to have commercial significance. Actually all micropaleontologists almost daily encounter fossils which they set aside, or discard, because they do not know their relationships.

Let me briefly cite two instances bearing on the point that we all see what we are looking for, and fail to notice those things we have not learned to understand. Dr. Paul Dunn of Mississippi State College has long been preoccupied with the arenaceous Foraminifera which occur in insoluble residues. Some years ago he was able to demonstrate the existence of such microfossils in his portion of a slab of Niagaran limestone, whereas several capable paleontologists had been unable to find the fossils in their portion of the same sample. More recently, on the basis of arenaceous Foraminifera alone, he has been able to identify Silurian rocks in a well in Mississippi.

A few months ago Donald Eicher of the Standard Oil Company of Egypt, who was trained in the study of conodonts and scolecodonts, discovered representatives of those microfossils in the "Carboniferous black shales" just above the Egyptian Nubian sandstone. Other stratigraphers have previously examined these shales, but because they have not been looking for conodonts and scolecodonts they, of course, have failed to see them.

Pedagogical preaching doubtless proves boring to most micropaleontologists. It should not, however, because, quite aside from the fundamental importance of these academic matters, whether the men who come to commercial laboratories are well trained or not may go a long way toward determining the success or failure of the micropaleontologist under whom they have to work. No doubt pedagogical prattle may also irritate some company officials. It should not, however, because whether the microstratigraphers they hire are well

trained or not may mean money in their company's pocket or red ink on its ledgers.

Such points would not be worth mentioning in this discussion were it not for the fact that the idea is prevalent in certain quarters that anyone, whatever his background, can readily become a micropaleontologist. It is true that many persons of average intelligence, with or without formal training, can be taught to pick out and identify microfossils under a binocular. But this is not micropaleontology in anything except the most routine sense, and if the science is to progress either academically or commercially, a more comprehensive and intelligently thought-out training program is an absolute necessity. This is not alone true for the micropaleontologists, but for geologists as well. The Graduate Record Examination[5] bears out this point in some detail.

The Graduate Record Examination, a project begun in 1937 under the sponsorship of Columbia, Harvard, Princeton, and Yale Universities, in collaboration with the Carnegie Foundation, has now been given to more than 10,000 graduate students trained in more than 400 colleges. The results seem to indicate, among other things, that geology is attracting graduate students less well prepared generally in undergraduate days than those men who are entering a number of other scientific fields. This is not only a critical situation for the entire field of geology, and one which needs to be remedied at once, but it is particularly serious from the point of view of the science of micropaleontology. It is particularly serious because many students approaching their master's or doctor's degree suddenly realize that training in micropaleontology may serve as an entering wedge in securing employment in the petroleum industry. As a consequence, some of them have been permitted to enroll for courses in micropaleontology, despite the fact that not any of their previous training has qualified them for the work. There is no denying that many such persons do find employment in some microstratigraphical position. If they are natively intelligent, they may even do surprisingly well in this field, but certainly they would do very much better had they been given the proper curricular background. Furthermore, petroleum geology generally would be greatly benefited if some qualifying test could be set up so that the graduate students fed into the petroleum business from the universities could be men not only of adequate scholastic attainments but even more important, men of a high type of intellectual potentiality, which is, of course, a very different thing.

[5] The entire problem of geological and micropaleontological curricula, because of space limitations, must be discussed in another paper.

NEW FRONTIERS IN MICROPALEONTOLOGY[6]

And now—what of the future? Of this only one thing is certain; namely, that the predictions will be couched in such general terms that, as in the case of the Delphic oracle, subsequent events are not likely to prove the prophet wrong.

At the moment, the relatively recent development of electrical logging methods seems to have thrown commercial micropaleontology into something of a decline; but it is far too early to predict the demise of the patient. Actually the future of the subject never looked more encouraging academically, and we may be confident that this merely means, after the inevitable time lag, better commercially.

The writer looks forward to the time when all micropaleontologists will be trained adequately in micromineralogy—(the micromineralogists would do well to reciprocate)—when they will be well grounded in statistical analysis and the theory of probability, and, finally, when they will have more than their present nodding acquaintance with zoölogy and botany. This may seem an almost impossibly broad background for all micropaleontologists to acquire; but at least it certainly is not too much to hope that future neophytes entering this field of specialization will be equipped with much more inventiveness in the search for new techniques and new ideas generally. If such an advance only could be achieved, we probably would find the science of micropaleontology rapidly forging ahead commercially despite the increasing competition it is certain to meet from ever-expanding physical methods of well logging.

It has already been indicated that new groups should certainly receive greater attention in future micropaleontologic studies. Many, but not all of the kinds of microfossils which merit this emphasis, but instead remain essentially neglected, are listed in the foregoing outline for a course in micropaleontology. To illustrate briefly, the Radiolaria have long been well known in general terms but, specifically, they are almost entirely disregarded. Actually these microfossils are much more common than is ordinarily suspected, in part because most micropaleontologists seldom examine carefully the material on, or passing, the 100 screen. With some of the new drilling techniques coming into more common usage, only thoroughly pulverized samples may be available for study from some wells. Under such circumstances some Radiolaria should still be preserved for diagnostic stratigraphical

[6] Owing to space limitations, this subject can only be presented in extremely abbreviated form in this paper. An article bearing the title of this subhead, however, is to be presented at the Fiftieth Anniversary Celebration of the University of Chicago on September 26 as a part of the Frontiers in Petroleum Geology symposium.

analysis, whereas many of the larger kinds of microfossils will be injured or destroyed.

Although the point is all too commonly overlooked, the science of micropaleontology could make many other significant contributions to petroleum geology in addition to its use as a tool in the examination of well cuttings, important as that may be commercially. The internal structure of the Radiolaria is such that its preservation in flints and cherts may be of use in solving such important sedimentological problems as the origin of some cherts and novaculites.

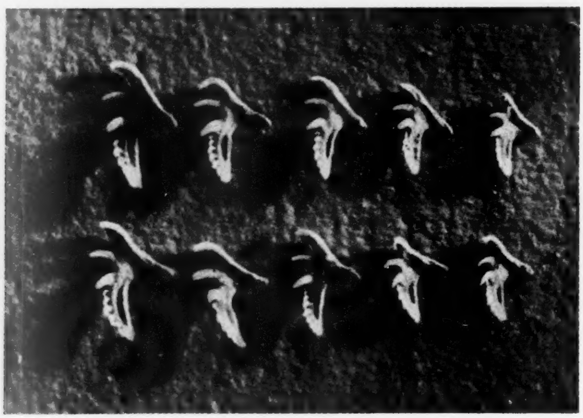

FIG. 12.—Ten scolecodonts of various sizes belonging to same "form species," or more properly to same *centuria*.

A number of years ago, the writer suggested that Miss Esther Aberdeen study the Radiolaria from the Caballos formation, Marathon basin, Texas. Dr. Aberdeen's results (1940) give some indication of what might be expected were the Radiolaria to receive the attention which they merit. Moreover, because some Radiolaria throw light on the type of environment in which they lived, their study may help solve some of the questions regarding ecological habitats obtaining while certain formations were being deposited. Obviously the paleontological literature on the Radiolaria is at present entirely too scanty.

Other microfossils which are even less well known, though commonly represented in sediments ranging in age from Ordovician to Recent, are worm jaws or scolecodonts. It has been objected that these micropaleontologic objects are all different one from another, and thus that they defy classification on sufficiently detailed a basis to be of

stratigraphic use. Illustrated in Figure 12 are ten individual jaws of different sizes belonging to the same "species," which are displayed in a single photomicrograph for the purpose of disproving this particular criticism. Of course, no true biological species is represented by such jaws, for the animal which possessed these hard structures also had other masticatory parts of far different appearance which ordinarily are classified as belonging to still other "species." This very point well illustrates the need for a non-biological classification for such fragments, and for all similar microfossils which are less than entities.

Some years ago (1938) the writer suggested the *Ordo militaris* or *Military Classification* for such parts of biological wholes. Inasmuch as the difficulties involved in dual classifications are general, it seems that some of the problems might be lessened if merely the incubus of the terms "genus" and "species" could be removed. A satisfactory basis for a utilitarian classification divorced from such terms was found in the classical divisions of the Roman army. This military classification, with its approximate Linnean equivalents, is repeated here.

Linnean	*Ordo militaris*	
	Singular	*Plural*
Class	Exercitus	Exercitus
Order	Legio	Legiones
Family	Cohors	Cohortes
Genus	Manipulus	Manipuli
Species	Centuria	Centuriae
Individual	Miles	Milites

The most important part of the *Ordo militaris* is, of course, the use of the terms which are equivalent to genus and species in the biological classification, namely, *manipulus* and *centuria*. The substitution of these terms may seem strange at first, but *manipulus* is easier to use, for instance, than "artificial" or "form" genus, and it involves no contradiction or misuse of words. Under the military system not only neglected fossil fragments, but also the entities of which they are a part, will have a better chance of achieving the importance which they deserve. Several reviews have indicated that there is some general acceptance of such an artificial classification by zoölogical authorities; and the scheme has applicability in biological and anthropological classificatory problems, as well as in micropaleontology. It seems obvious, therefore, that some such system must eventually be adopted. The necessity for its use in many micropaleontological groups, at present insufficiently described, need not be belabored. One such group, however, which is again coming to the front in micropaleontological investigations is that of the spores described in some detail as early as 1884 by Reinsch, by R. Potonié in 1932–35, and more re-

cently by Schopf (1938). Read (1941) has suggested that the type Pennsylvanian section should be the eastern coal-field area in which the American Carboniferous stratigraphy was first studied in detail rather than the marine neotype section of Kansas and Nebraska which

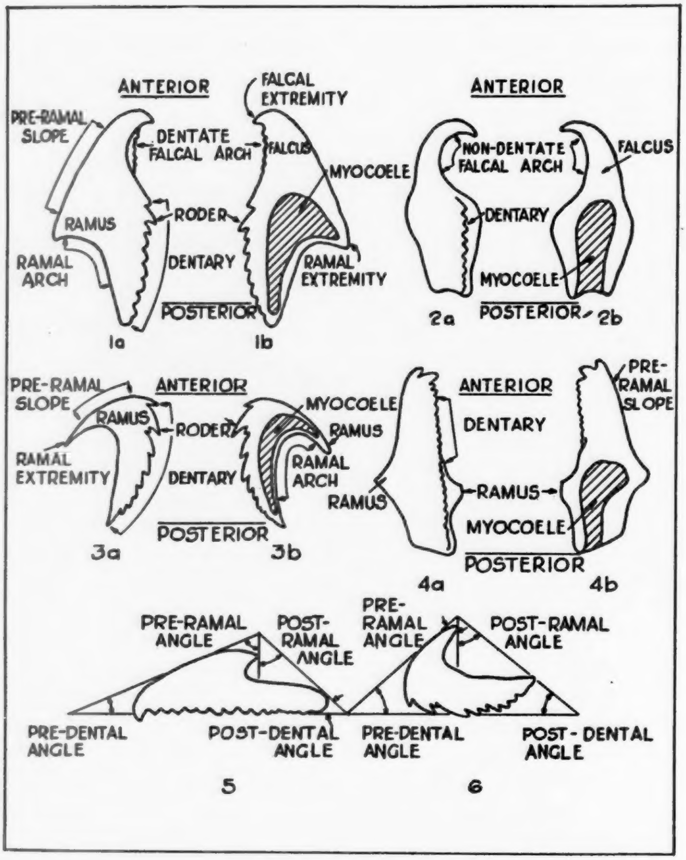

FIG. 13.—Scolecodont morphological features and their terminology.

is used as a reference by many stratigraphers. Although an increased study of spores might not settle this particular controversy, it doubtless would go a long way toward simplifying some of the correlation problems involved in it, as well as in related moot questions of the equivalency of spore-bearing beds deposited under somewhat different conditions, and in different provinces.

There should also be made available much more detailed descriptions of the distinguishing features of such fragments of entities, whether they be of plant or animal origin, so that they may be described more uniformly and thus achieve greater utility in the hands of micropaleontologists everywhere. This point is illustrated in Figure 13, which shows that scolecodonts have at least as many, if not more, variable features of classificatory importance as some of the megascopic invertebrate types such, say, as the gastropods.

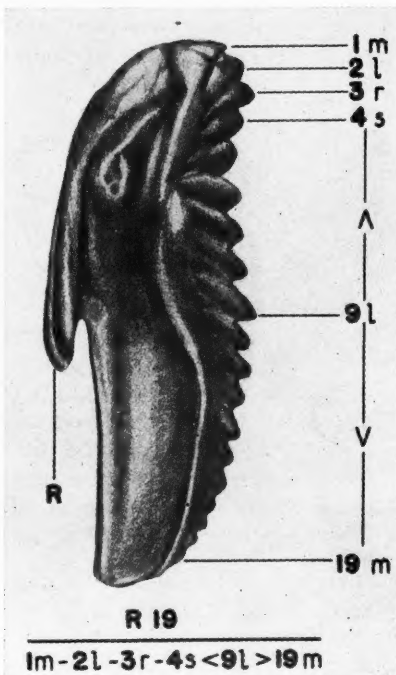

FIG. 14.—Dental formula for typical scolecodont.

We also need for all micropaleontologic groups, and especially for facilitating statistical analysis—which is destined to play an increasingly important role in the science—more accurate but still easily employable symbolisms. Figure 14 shows how a formula may be set up to express succinctly the dental arrangement for a typical scolecodont. With a little experience such a formula instantly creates in the mind of the worker a mental image of the form described by the symbolism.

The ontogenetic development of a number of the invertebrate animals as represented by protaspid trilobites, or the early growth stages of blastoids, as shown in Figure 15, should be studied far more extensively in micropaleontology. The importance of such investigations to zoölogical as well as paleontological theory can scarcely be overstated. Moreover, many such studies could be carried on by commercial paleontologists if they merely would make more general a fine practice that some of them already follow, namely, the setting aside for later study of as many of the microfossils not being used directly in their own stratigraphic work as is possible during the rush of commercial analysis. Such a practice slows up routine procedure only

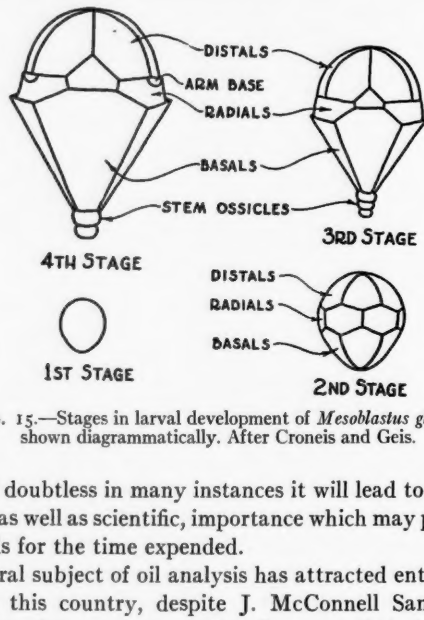

FIG. 15.—Stages in larval development of *Mesoblastus glaber*, shown diagrammatically. After Croneis and Geis.

slightly, and doubtless in many instances it will lead to discoveries of commercial, as well as scientific, importance which may pay rich financial dividends for the time expended.

The general subject of oil analysis has attracted entirely too little attention in this country, despite J. McConnell Sanders' English studies of some four years ago. Happily, some little interest in this line of investigation seems to be awakening in the United States, but so far as the writer is aware commercial concerns have thus far done no more than toy with the idea of carrying on research projects in the field. Figure 16, which is Plate 5 of Sanders' paper, is reproduced here merely to indicate what may be expected from such research.

Not only should much more investigation of the oils themselves be undertaken, but oil-field waters generally should be re-examined for their micro-organisms, for the micropaleontological possibilities of

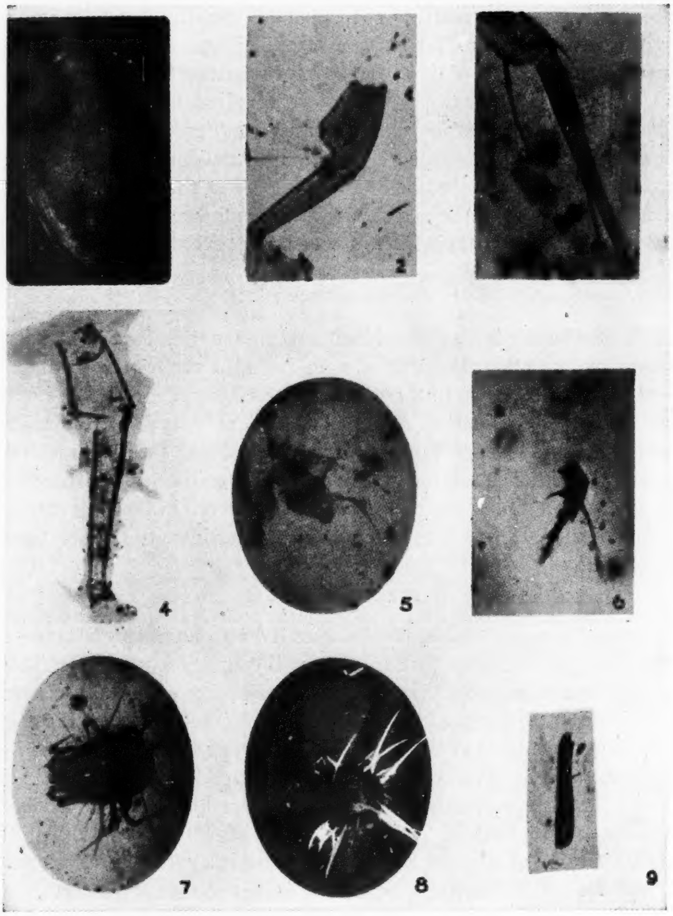

FIG. 16.—Plate V of Sanders' paper on "The Microscopical Examination of Crude Petroleum," showing a few of the more unusual micropaleontologic objects to be expected in crudes.

1. Silicified *Cyperus* fruit, Miocene oil, Assam. (×41)
2. Crustacean limb, Miocene oil, Sarlat, Mexico. (×640)
3. Crustacean limb, Eocene oil, Tamantao, Mexico. (×480)
4. Crustacean limb, Miocene oil, Sarlat, Mexico. (×740)
5. Insect remains, Miocene oil, Sarlat, Mexico. (×167)
6. Insect remains, Eocene oil, San Marcos, Mexico. (×196)
7. *Acarina* sp., core from Jurassic well, San Manuel, Mexico. (×75)
8. The same by polarized light. (×75)
9. Insect appendage, Pliocene oil, Moreni, Roumania. (×175)

oil-field liquids have scarcely been touched. Finally, due to improved techniques and devices for bottom sampling, such as the Piggot gun or some modification of it, as well as improvements in chemical, physical, and biological studies of waters, we may look forward to the time when micro-oceanography can join microstratigraphy in the all too slow march toward complete three-dimensionalism. S. W. Lowman's excellent paper presented before this Society at the Houston convention indicates that if the march has not already begun, the leaders are at least marshalling their forces for the maneuvers.

CONCLUSION

In conclusion, it may be said with assurance that if we want micropaleontology to flourish we must not—from the academic side at least—think too directly in terms of its commercial applicability. If we can produce really educated, resourceful, and ably imaginative micropaleontologists—or geologists—or geophysicists, for that matter—they will take care of the applications themselves. If we can only teach students to use their heads, we may be certain that, on entering the profession, they will use them in the oil business to the great good fortune of all.

ACKNOWLEDGMENTS

In such a paper as this, involving as it does a number of statements concerning the development of a field still young, the writer is naturally indebted to numerous persons for contributing essentially contemporary data. He is especially grateful, in this connection, for the coöperation received from Professors H. N. Coryell, J. A. Cushman, J. J. Galloway, F. B. Plummer, and H. G. Schenck. In addition, Miss Alva C. Ellisor and Miss Hedwig T. Kniker kindly made available important information. The writer also wishes to make explicit the valuable assistance given by his former student, R. V. Hollingsworth of the Shell Oil Company, especially in connection with certain aspects of commercial development of microstratigraphy. Most of the information contained in the paper, however, has been gained either through personal contacts or from articles whose authors, cited in the bibliography, must be thanked for inadvertently permitting the present writer to borrow so extensively from their works.

Finally, forgiveness is asked of all those who may have contributed yeoman service in the founding of the Science of Micropaleontology, but whose names were omitted from the text, or whose contributions may have been unintentionally minimized, magnified, or misinterpreted.

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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THE FUTURE OF GEOPHYSICS[1]

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The petroleum industry may well take pride in the fact that it stands to-day in a position, shared with few others, of being able to supply easily whatever demands may be made upon it by reason of the present national defense program; and at the same time, it can assure the nation that its future supply of oil is insured by a proved domestic reserve greater now than at any time in the past.

Geologists, geophysicists, and all others concerned with the exploratory activities of the petroleum industry, must of necessity be more concerned with future possibilities than with present realities. We are quite justified in congratulating ourselves upon our present accomplishments, but only because past successes enable us now to look ahead to a difficult but orderly exploration program, rather than a frenzied, inefficient scramble for immediately needed oil.

I like to think of the exploratory activities of the industry as the expression of its instinct of self-preservation. The continued existence of the industry is dependent upon our success in finding to-day the oil of to-morrow. It follows that there will be no appreciable change in the magnitude of exploration activity, whatever form it may take, until that yet far distant day when no then-known exploration technique is economically applicable to the finding of those fields remaining undiscovered. We all may hope, and I may be permitted to believe, that the end, when it comes, will not be far short of the ultimate end point when all oil fields at producible levels have been discovered.

Obviously the techniques of exploration must continue to improve or expand and the art of applying those techniques must improve if the future discovery rate is to be kept on a par with that of the present. Improvements there certainly will be, expansion is probable; but I believe that the greatest advances in the art of exploration in the near future will come through the more effective application of the now-existing techniques of geophysical prospecting. Lacking that hypothetical being, the geophysicist of the future, who will possess all the abilities of both our professions, it is necessary that the geologist and

[1] Address of the president of the Society of Exploration Geophysicists before the joint meeting of the American Association of Petroleum Geologists, the Society of Paleontologists and Mineralogists and the Society of Exploration Geophysicists at Houston, April 3, 1941. Reprinted, by permission, from *Geophysics*, Vol. 6, No. 3 (July, 1941).

[2] Geophysical Research Corporation.

the geophysicist learn to complement each other's efforts to a degree now only approached.

It is often true that an individual's faults and his virtues are but different expressions of the same character trait. I admire my friend who is strong-minded; but I dislike the man who is simply bull-headed. So it is with us, as professional men. The really great geologist of to-day, or of to-morrow, is the man whom DeGolyer has so well described as the "speculative geologist," the man who can take a meager number of facts and by an inspired generalization, point out an area of great possibilities. Yet that very ability to generalize, if not carefully controlled, can lead the same individual to condemn an extensive area because of the lithological characteristics of the formations penetrated in a few scattered dry holes. The geophysicist, knowing from his seismograph work, that some physical properties of the section can change, and do change greatly in a relatively short distance, naturally objects. Similarly, the geologist must sometimes feel that the geophysicist's only criterion of a favorable area is "can reflections be obtained?" and may feel that the geophysicist would just as soon map an igneous sill as an oil sand. Furthermore, the geologist must sometimes become impatient with the geophysicist's reluctance to commit himself to a definite "picture" based on data whose probable error is great.

Since no oil fields will be discovered in an area never explored, and since inaccurate geophysical work may be worse than none at all, I believe we may reasonably say that the best team of the future will be an optimistic geologist and a pessimistic geophysicist—pessimistic in the sense that he will scrutinize his results with care and refuse to allow himself or others to consider them to be better than they are.

In my opinion, domestic seismic activity will continue for at least five years at about the same level as at present, that is, with between 150 and 200 crews in the field. How shall they be profitably employed? Undoubtedly we shall continue to resurvey old areas for minor structures. Work of this type is being proved very successful in central Oklahoma. It is encouraged by the accurate data now obtained at reasonable cost, and by economic considerations. As the production of wells in an old area decreases, there is less difficulty in obtaining a fair allowable for new wells, and so more incentive to drill them. Naturally the companies who will profit most from such work are those who have already made dependable widespread surveys of the areas concerned, rather than those whose past efforts have been confined to spot shooting in "hot" areas. Just as the subsurface work of the geologist is never finished, so the work of re-examining the seismic picture of an area need never come to an end.

It is reasonable to expect that a considerable part of the much-surveyed Gulf Coast area will be seismographed once again to map deeper horizons. This can be done with only minor modifications of the present technique. Certainly the situation now existing should be corrected. I refer to the fact that the average depth to which the Gulf Coast has been seismically surveyed is less than the depth of many wells now being drilled. In planning a program of deeper exploration one fact should be kept in mind. As the depth to a reflecting layer increases, the accuracy of the dip-shooting method decreases, and the resolving power of the correlation method also decreases. These physical phenomena should please both the structure-minded and the trap-minded geologist. The former may be assured that the structures discovered will show ample closure; the latter that the program will delineate major faulting, unconformities, and regional features which will afford material for speculation and possibly call for revision of present ideas.

It seems certain that much of the seismic work of the future will be directly concerned with the location of stratigraphic traps. This statement may easily be disproved by simply defining a stratigraphic trap as one having no association with structure. However, if we use the term, as is commonly done, to include such accumulations as East Texas, then it can not be said that stratigraphic traps are nowhere associated with structure. A similar comment was made two years ago before this group by F. M. Kannenstine, then president of our Society. I prefer to think of a stratigraphic trap as one in which the accumulation is limited in at least one direction, by something other than structural relief. A sand lens would then typify a pure stratigraphic trap. A pinch-out of a reservoir sand on a structural nose would then also be considered a stratigraphic trap of a less perfect type. Certainly, such noses can be contoured by the geophysicist, and the geologist may be able to state with considerable certainty that a pinch-out is to be expected. Actually, the program should be reversed; the speculative geologist may indicate a zone in which a pinch-out of a possibly productive sand should occur. The geophysicist may then look for structure. Neither, at present, can be expected to indicate with certainty the exact point updip at which the pinch-out occurs, or the exact location of the water line downdip, although it is conceivable that even this may be possible in some places. The aid of the exploratory drill will ordinarily be needed, but it is also needed to locate flank production on salt domes. It is not of record that this fact deterred us from using geophysical methods to locate such salt domes. The Coalinga Nose field and the similar but smaller East Coalinga field of Cali-

fornia are typical examples of the type of trap here discussed. The discovery of the latter resulted directly from a geological surmise followed by careful geophysical work which located the nose.

The application of geophysical work just discussed is mentioned first because it not only can be used, but it has been used. Other applications of the seismic method to the location of stratigraphic traps can be suggested. Updip convergence of the seismic horizons bounding a section known to contain productive zones, may well point to the approximate location of a pinch-out. It is easy to depict a hypothetical case of this sort in which the pinch-out could be indicated with fair accuracy.

The geophysicist should be encouraged to speculate with hypothetical cases of this sort; the geologist is well advised to join with him. I believe that both would profit also by studying together the subsurface picture of known stratigraphic traps. If the geophysicist feels, upon studying such data, that he may be able to delineate a few of the known traps, it would be well to allow him to try to do so, purely as an experiment. In fact, I believe that it would be quite worth the cost to conduct a few seismic surveys over a number of known stratigraphic traps in the hope that the opportunity of comparing the results obtained with the known conditions might enable similar conditions in the same areas to be recognized. Certainly, some experimental work of this sort should be done before concluding that the seismic method is not applicable.

It is fortunately no longer necessary to emphasize the importance of structures of low relief, but it still requires courage to drill them. In considering the validity of minor anomalies it is well to ask whether they are indicated by a pessimistic interpretation of the data. If so, they are real anomalies, and their significance must be considered, remembering that the significance of a structural anomaly is relative to some pre-conceived standard. The insignificant anomaly, as judged by the standards of to-day, may well be judged a good prospect to-morrow. Even in spite of the general realization of this fact, I venture to state that many of the oil fields of to-morrow are already indicated on the better seismic maps of to-day as anomalies now considered too weak to test.

My personal specialty in the field of geophysics does not qualify me to suggest new provinces in which the seismic method may be used to advantage in the future. I am more concerned with those known provinces in which the method is relatively unsuccessful. These are of two main types, one in which the surface material is a high-speed material, for example, the Cretaceous limestone of the Edwards Pla-

teau. The other is one in which accurate mapping is required on two or more closely adjacent beds, too close together to be resolved with the present technique. In the solution of these problems lies a great possibility for future progress. Although considerable experimental work has been and is being done, much more should be done. The phenomena with which we deal are extremely complicated, and no one can say that even a more complete understanding of the properties of the earth will enable us to solve these problems. Nevertheless, I feel that more time and money should be spent on both research and experiments dealing with the fundamental properties of the earth and the propagation of waves therein, for in that approach lies the best chance of improving our technique.

Gravimetric surveys with the gravimeter will continue to be an important reconnaisance method but it is not likely that the activity will continue long at its present level. The gravity meter permits blanket coverage of extensive areas at moderate cost. If an original survey is properly conducted, the area need never be covered again.

It is probably too early to determine the value of the extensive, detailed surveys now being made. The great sensitivity of the gravimeter and the close spacing of stations customarily used results in the mapping of both major and minor anomalies, many of which are difficult of interpretation. The data now being obtained will be available for use in the future, when it is reasonable to expect that the physical significance of various types of observed anomalies will be better understood. In the meantime, the instrument will undoubtedly be used largely empirically, as a method of locating anomalies to be investigated by the seismic method. No further improvement in the gravimeter or in the technique of its use is needed. The difficulties encountered are entirely in the interpretation. The instrument can and, I hope, will be used in locating piercement-type domes, undoubtedly existing offshore on the Gulf of Mexico. The day may yet come when a method will be found to develop oil fields so located.

I look for little change in the status of electrical methods of exploration. Future progress in their use can come only from a better understanding of their limitations and in the better recognition of areas suited to their use. The theoretical background of electrical prospecting is excellent and the theory has repeatedly been checked by experimentation. In spite of this, few other methods have been more misused and an enormous number of ill advised empirical tests of various systems have been made.

Electrical methods employing high-frequency alternating current, or short electrode spacings, can delineate only surface or near-surface

features. In particular, the depth of penetration of currents of radio frequencies into earth materials of moderately low resistivities, is extremely small. Systems employing direct or very low-frequency alternating current may be used to map a bed at moderate depth in a few regions of simple geological structure. A suitable section is one in which a massive bed of high electrical resistivity is overlain by a fairly homogeneous material of lower resistivity. To work at depth, it is essential to use current electrode spacings three to five times the depth of the layer to be mapped.

These well-known principles are mentioned only to emphasize the necessity of the proper use of electrical methods. While they should continue to be considered as possible techniques, they should be used only in areas where information concerning surface features is known to be of diagnostic value, or in areas of extremely simple structures of a few particular types.

It has already been said that the unsolved problems in the field of seismic surveying require for their solution a more complete understanding of the properties of the earth strata with which we deal. The development of new methods of geophysical prospecting must similarly result from research work on fundamental problems. In fact, the development of a new method would seem to be dependent on the recognition and evaluation of physical properties of the earth not delineated by any of the present methods. A new prospecting method is not likely to spring suddenly into being. The spectacular rise of the existing methods, sudden as it seemed, was based on a substantial background of theoretical and experimental work in allied fields. The possibility of utilizing the gravitational, magnetic, and acoustic properties of the earth in structural prospecting was recognized for many years before practical methods were evolved. The successful use of gravitational methods was made possible by the development of the Eötvos torsion balance. Similarly, the development of the seismic-reflection method was made possible by the availability of the vacuum-tube amplifier.

Most of the development and experimental work in the field of geophysical prospecting during the past fifteen years has been aimed toward improving instrumentation and field technique. This type of work has resulted in the development of the precision pendulum, the gravimeter, and in numerous developments in seismograph equipment. The cost of this work has been amply justified by the resulting reduction in prospecting costs and by the increased accuracy of the data obtained. The instrumentation and techniques of the existing methods have now reached a high state of perfection, but our understanding of

many of the phenomena encountered in the practice of these methods is still lamentably imperfect. In the future, more time and money should be spent on research work on fundamental problems. Development programs promising immediate returns, are superficially more attractive than broad research programs, the specific results of which are unpredictable, but only broad programs can result in major advances. The value of a research program is cumulative, and the economic value of any particular investigation may not be apparent for years after the work is done. As our background of fundamental knowledge increases, the necessity of subjecting suggested new methods to empirical tests will decrease. Empirical trials of new methods are tremendously expensive and time-consuming. While a certain amount of empirical work will always be necessary, even a moderate reduction in the amount of such work can result in savings sufficiently great to pay for a large amount of basic research.

The development of a direct method of locating oil is an ever present hope but no proved method at present exists. Empirical trials of geochemical methods are now in process but no conclusive results are as yet available. The work being done with these methods illustrates very well the difficulties encountered when a theoretical or experimental background for a new method is lacking. While some of the reported results of these methods are encouraging, much more empirical work must be done before they can be accepted or rejected. In the meantime, work on the fundamental problems of the origin and manner of accumulation of oil should continue to be pursued actively, since the solution of these problems is essential to the logical development of a method of locating oil directly.

Although the geological and geophysical staffs of the oil industry have the finding of oil as their primary function, both can be of assistance in problems connected with the drilling of wells and the production of oil. The aid given by the geologist is already extensive, that of the geophysicist will become increasingly important. The knowledge of earth properties gained by both field and laboratory work and many of the techniques developed in exploratory work can, and will, be increasingly applied to problems outside that field. The electrical logging of bore holes is, to date, the outstanding example of the use of geophysical data in production problems. The recent introduction of radioactivity logs of bore holes is another contribution of the geophysicist. The sonic method now used to locate fluid levels in producing wells is an application of a technique used in seismic surveying. It is certain that other contributions will be made in the future by the technical staffs associated with the geophysical departments of the in-

dustry, and that the geophysics of the future will embrace a far wider field than it does at present.

It is to be hoped that the disturbed world conditions will not be allowed to interfere with the development of the geophysical arts as applied in the oil industry. While the harmful effects of a decrease in geophysical exploration or of serious interference with the normal progress of the art will not be immediately apparent, the long-term effects can not be viewed with equanimity. However dark the present may look, as individuals and professional men, we must never lose sight of the fact that our efforts of the present are of value only to the extent that they insure for us the future which we desire.

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PETROLEUM AND THE WAR[1]

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In addressing an audience such as this, it is hardly necessary to stress the importance of petroleum in modern mechanized war—in fact, while it is hardly possible to over-emphasize this importance, any spokesman for the industry should couple any such emphasis with a factual picture of the industry's ability to meet all this country's needs. Otherwise, there is a tendency to stimulate unwarranted fears of shortage and unnecessary proposals for additional control or regulation of the industry.

On the other hand, when we view the petroleum picture from the standpoint of the incomparably smaller petroleum reserves of Europe, it is unquestionably true that both the strategy and the tactics of the present war are to an increasing extent being determined by the quantity and quality of petroleum supplies available to, or desired by, the various powers. The tremendous difference in the relationship of petroleum to warfare in this country and among the Axis powers is best illustrated by the simple fact that Germany and Italy have been carrying on their war operations, plus the industrial, agricultural and civilian activities of these two countries and the occupied territory of Western Europe, with a total production of petroleum products, including synthetic products and imports, equal to *only about 5 per cent* of this country's production of crude or our consumption of refined products.

I shall reserve a detailed discussion of the Axis supply situation until the close of this paper and proceed first to an analysis of our own supply and demand situation as related to our defense program.

OUR PROGRAM OF MECHANIZATION

All of us are generally familiar with the rapidly expanding program of our navy, culminating in a real two-ocean navy of unmatched fighting power which will be almost entirely dependent upon fuel oils from petroleum as its driving force. The spectacular development now under way for our air services is also well known, and all new fighting planes are designed to take advantage of synthetic superfuels not even dreamed of a few years ago. Military plane production in this country is now over 1,000 units per month and this will be almost doubled by

[1] Read before the Association at Houston, April 3, 1941.

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this summer, and trebled by next spring. What this really means as to extent of expansion is emphasized by the fact that our commercial air lines, of whose development we are justly proud, has a total of less than 400 planes in service. We are so accustomed to large numbers that we hardly realize what it really means to build two or three thousand planes a month. Of course, even this by no means represents all the potential plane-building capacity of our nation.

Less fully appreciated is the tremendous program being undertaken looking toward the mechanization of our land forces. Although our rather late start in this direction has its disadvantages, it has permitted us to take advantage of the most recent technical developments and the latest experience from abroad. Once our tremendous mass production facilities are brought into action, we shall be building a quality and quantity of tanks, trucks, and armored cars which will amaze the world. If land defense of this country should ever become necessary, this equipment, using our unequalled system of highways and our widespread and efficient gasoline-distributing system, will give the nation a flexible defense system better than several Maginot lines. Just as one great advantage of cavalry was its ability to live off the country, so the petroleum industry's maze of distribution facilities, bulk plants and filling stations will help to supply our mechanical horses with the hay they need, especially insofar as the military equipment is designed to utilize the fuels which are generally available.

To quote from a recent speech by Assistant Secretary of War Patterson—

> All animal-drawn transportation is being replaced so far as practicable with motorized equipment. This does not mean that the death knell of the horse has been sounded, or of the army mule either. But of the 27 divisions in the continental United States, 25 now rely entirely on motor transport for tactical operation and supply. The field trains of our cavalry divisions have been motorized. And as a final indignity to the horse, our cavalry reconnaissance regiments are partially motorized and are equipped with motor trailers for the transportation of their horse elements.

General Barzynski, who is in charge of motor transport for the Quartermaster, recently stated that a year ago they had only 14,000 vehicles; to-day they are maintaining approximately 75,000 vehicles, which will increase to 190,000 by June 30, and 286,000 by late summer or early fall. This is the number now considered necessary for an army of 1,400,000 men.

While all this sounds like a large program which would have a tremendous effect on the petroleum industry in this country, actually when it is measured against the background of the size to which this

industry has grown since the last war, it is relatively small. As a matter of fact, the purely military demand to date has not offset the loss of exports due to the war. However, these increasing demands are making themselves more and more felt as the year progresses, together with substantial increases in industrial demand and civilian demand from the new employees of industry. We estimate that in the absence of war the 1941 domestic demand for petroleum will be about 9 per cent in excess of the 1940 demand, and that in the event of war toward the end of the year the demand for the major products would be increased about another 5 per cent.

In my opinion no industry of comparable importance to defense has so few even potential bottlenecks as has the petroleum industry. The ability of every branch of the industry to answer "Ready!" means much, both to national defense and to our national economy as a whole. To illustrate this, let us consider the situation which prevails in the different branches of the industry.

PRODUCTION

The outstanding development in the producing end of the industry since the last war has been the general adoption of proration policies designed to conserve the reservoir energy and insure greater ultimate recovery of oil from a given formation, and a more equitable division of this recovery among the different land owners. From the standpoint of its effect on petroleum supply, this operation is analogous to the building of dams on mountain streams to control the wasteful spring floods and insure a steady and continuing supply as it may be needed during the dry seasons. As a result of this policy of proration, the producing branch of the petroleum industry is particularly well prepared for any emergency. During the last war the price of crude had to be increased very substantially in order to encourage more wildcatting and the drilling of many new wells. This, plus the general increase in the prices of products, resulted in large temporary profits for the industry, but it has not yet forgotten the headaches of the long morning after. To my mind, one of the most constructive features of our whole defense program has been its definite policy of endeavoring to prevent the vicious spiral of "higher prices for everything" from getting started.

To-day those states which have practiced sound conservation principles have built up tremendous underground reserves, available at a moment's notice for practically any emergency—and this without putting an extra load on the overburdened steel industry or the labor market to drill thousands of new wells. You may well guess that any-

one locating new refineries or industries based on petroleum would naturally favor such states over those which have squandered their assets and have only a declining production to look forward to.

We have recently assembled detailed state-by-state estimates which indicate that, without any excessive drilling programs, production could be increased by 30 per cent and maintained at this figure for at least 2 years without any major new discoveries.

Of course, the industry must not relax its normal activity toward making new discoveries, although it should avoid unnecessary drilling and unsound well-spacing programs which use up capital, labor, and steel to no useful purpose. New wells and fields must be discovered and connected up and new pipe lines built as old fields decline. I am sure that if our producers are given freedom of opportunity, subject to the limitations of sound proration regulations, they will see that every possible demand is met for many years to come.

REFINING

In refining, the possibilities of immediate expansion of output to meet sharp increases of demand is not quite as great as in production; but, nevertheless, our civilian demand is so large that it still dwarfs every possible military demand, even though a few special products require special attention. Few, even in industry, realize that the increase in our gasoline production has been about twelve-fold since 1916. Our unused refinery capacity of approximately 1 million barrels daily is greater and more efficient than was our entire capacity in 1917. It would be possible, by rather moderate methods of reducing civilian consumption, to meet all military demands without any increase in refinery operations, but the petroleum industry would not consider that it had done its duty by its country or its customers if this had to happen. When in most cities, except a few along the northeastern seaboard, around 50 per cent of the individuals entering the central zone of the city do so by means of gasoline, and motor transport is so essential to both industry and agriculture, we can not lightly talk of curtailing civilian consumption as though it could be done as readily as in Europe. Also, the loss of excise taxes and income taxes from the oil, motor, and rubber industries would have a very adverse effect on Federal and State income at a critical time. If we are to avoid such a possibility, the industry must at least keep its refineries expanding fast enough to keep pace with the growth of peacetime consumption and keep the customary reserve of 20 to 25 per cent of shutdown capacity available for emergency wartime needs, for which purpose it is more than adequate. As new and more efficient refining equipment is de-

veloped and installed, the old should, so far as possible, he held in reserve for emergencies.

100-OCTANE AVIATION GASOLINE

Coming to the specific refinery products, the problem which has given us most concern in planning to meet the army and navy demands is also one of the most romantic stories of our industry, namely, synthetic 100-octane gasoline. Although the advantage of high-octane gasoline in making possible higher-compression engines has long been understood, the appreciation of its tremendous value for aviation purposes is somewhat more recent. In aviation, the more efficient high-compression engines have three advantages—first, a smaller fuel load; second, a lighter engine per horsepower; and, third, less head resistance due both to a smaller engine and a lower cooling load, because more heat is converted into work and less into heat to be rejected to the atmosphere. All of these mean higher speed and/or greater load-carrying ability, both of which are almost priceless for military purposes. For example, a difference of only 25 miles per hour in the top speed of two fighting planes gives the control of the attack or retreat to the faster plane.

While ordinary motor gasoline was making its steady climb from 50 to 55 octane during the last war to around 75 octane at present, far-sighted representatives of the military services and of our industry were focusing their attention on the apparently unattainable goal of 100 octane for military aviation. In a suitable supercharged engine, 100-octane gasoline makes it possible to get 20 to 25 per cent more power from a given engine than can be obtained on 90-octane fuel such as that available to the Axis powers. This 100-octane fuel, which ten years ago was available only in laboratory quantities at a price of $10 per gallon, can now be made by any one of several newly developed synthetic methods, and is available in large quantities at around 16¢ per gallon f.o.b. refinery. The principal raw materials for these synthetic processes are certain constituents of cracked refinery gas, available in suitable quantities in almost any large refinery. Our country is of course unique in the tremendous quantities of such gas which are available. The final 100-octane gasoline usually contains some fairly high-octane straight-run gasoline and other constituents, including not more than 3 ml. of tetraethyl lead.

Fortunately for the defense program, the petroleum industry, with its genius for overbuilding, has already installed synthetic capacity equal to nearly twice the present domestic and foreign demand, so there is to-day substantial excess capacity available for the building-

up of a reserve for possible war demand. The present capacity is, however, barely enough to meet our probable peacetime requirements, including export, once our training program is fully under way, and not enough to fully meet present estimates of full wartime demand after our plane-building program is complete. Revised specifications have recently been issued and others are being investigated, which should increase the quantity available without any adverse effect on performance. The importance of building a stock pile now, while we do have some surplus capacity, seems obvious, and a substantial start in this direction has recently been made by the army and navy. While recently announced increases in capacity will cover all prospective demands for the next 15 to 18 months, we would like to see still more capacity built to take care of possible contingencies and also make it possible to improve further the octane rating of the gasoline used by the military services and give them a further competitive advantage.

LUBRICATING-OIL REQUIREMENTS

The lubricating-oil requirements of the aviation and the army mechanization programs will also be very substantial; however, insofar as we have been able to develop them, they will not be much greater than the export demand which has been lost. Efforts are under way to reduce the number of different specifications for lubricants and thus simplify the problem of supplying the needs of the army in particular.

HEAVY FUEL OIL FOR THE NAVY

Heavy fuel oil for the navy is a problem to which considerable study has been given. For a naval war in the Pacific, industry stocks and underground reserves are both more than adequate, but for a possible major effort in the Atlantic, industry supplies from domestic sources would not be adequate to meet both naval and industrial demands, even if allowables were increased on the few relatively heavy crudes available east of the Rockies. For this reason we have recommended that the navy build up substantial additional reserves of fuel oil on the east coast and at the proposed new bases. Fortunately, if an emergency should develop before such stocks are acquired, east-coast demands could be met by shipments from California or the importation of heavy crudes and fuel oils.

HELPING TO ELIMINATE BOTTLENECKS IN OTHER INDUSTRIES

As indicated, the petroleum industry is surprisingly free of bottlenecks, and even those which now appear can readily be taken care of

in one or more ways. However, our ability to supply large quantities and a wide variety of cheap hydrocarbons means that we will be more and more called upon to help eliminate bottlenecks in other industries which need hydrocarbons for raw materials. Two examples which are of major importance are toluene for TNT, and synthetic rubber. The supply of toluene from coke ovens is not sufficient to meet military demands, but these demands can readily be met from petroleum raw materials, without the runaway toluene prices which prevailed during the last war—in fact, overlooking capital cost, the petroleum industry can make more than enough toluene to meet all needs at costs lower than present toluene prices. Synthetic rubber also can be made more cheaply from petroleum than from other raw materials, and at costs not far above the present price of the natural product. The production of other chemical products starting from petroleum raw materials is also being rapidly expanded.

TRANSPORTATION

So far as the transportation of crude is concerned, there is adequate capacity in existing pipe lines to take care of any reasonable expansion, but it will, of course, be necessary to continue to build new lines into new fields and supplement lines into fields where the production is increased. If crude production should have to be increased suddenly by increasing allowables in certain states, some new lines probably would be needed to get this crude to points where there was available refinery capacity. As a matter of fact, we are somewhat concerned by the fact that the great bulk of the readily available increase in crude supplies would have to come from points south of the Red River, while the spare refining capacity is widely scattered over the country. We expect to undertake shortly a detailed analysis of this situation.

Gasoline transportation by tank car and pipe line in the interior of the country is also capable of handling a substantially increased load without difficulty.

In spite of the fact that American Flag tanker tonnage is 20 times that in the last war, our most serious possible bottleneck is in tanker transportation facilities to the east coast, which is not adequate to take care of any sharp increase in demand except by the curtailment of civilian supplies. Fortunately, about 25 large tankers are due for completion this year, but they will not much more than take care of this year's probable growth in demand plus the tankers which have been and are likely to be requisitioned for service with the navy. In view of the possibility that interference with tanker

transportation on the east coast might well coincide with emergency demands, we have recommended to the industry the development of all possible supplemental methods of transportation to the east coast. It is fortunate that private capital stands ready to construct two gasoline pipe lines into the Southeast if legal obstacles can be eliminated. It seems inconceivable that one interstate carrier which employed the right of eminent domain to secure its own right of way should be permitted to use that right of way to block a competing interstate carrier. It is equally difficult to understand how the Georgia legislature could turn down the unanimous request of the President plus the Secretaries of War, Navy, and the Interior, urging that enabling legislation be passed to make possible the prompt construction of these facilities which are so important under the emergency conditions we are facing.

STORAGE PROBLEMS

In addition to augmenting our transportation facilities, the possible emergency situation facing us demands the construction and filling of still more storage along the Atlantic Coast. Not only will this help to iron out the peaks and valleys in tanker demand, but in preparing for an emergency excess crude and refining capacity is no substitute for *finished products* located near the point of consumption. It is disturbing to note that gasoline stocks at Atlantic ports during recent months have been lower than at the corresponding period of any of the last 4 years. Whatever may be said about the undesirability of large stocks in normal times, under present conditions I do not think there is any such thing as too much of petroleum products along the Atlantic Coast, and I urge that the industry use every effort to build these up during the next few months.

The adequate protection of such storage facilities from possible bombing attack is a matter that has given concern to both the Federal and State agencies. At our request, the American Petroleum Institute has appointed a number of regional committees to study this question and to confer with the army and navy representatives in the various areas, both from the standpoint of protecting the industry supplies and of protecting congested areas or harbors from the results of possible attacks.

A committee of seven expert terminal engineers, loaned by oil companies in different parts of the country, has been coöperating with the Petroleum Section and the army and navy in developing economical designs and desirable types of locations for the storage, by the two services, of reserve stocks of products such as aviation gasoline and

fuel oil. It is anticipated most of such storage will be placed underground, particularly at the more exposed locations. Underground storage of much of the widely scattered industry's stocks would not seem to be either feasible or necessary.

PETROLEUM-SUPPLY SITUATION OF AXIS POWERS

To properly evaluate the probable petroleum-supply situation of the Axis powers to-day, it is necessary to start with the basic picture of the world distribution of crude-oil production. These rather surprising figures are set forth by appropriate subdivisions in the following table.

TABLE I

1940 Crude-Oil Production by Areas*

	Barrels per Day	*Per Cent of Total*
United States	3,692,000	63.0
Other Western Hemisphere	866,000	14.8
Russia	593,000	10.1
Near East	335,000	5.7
Netherland E. Indies	166,000	2.8
Roumania	118,000	2.0
Germany,** Poland, Albania, Japan, Hungary and France	43,000	0.7
Rest of World	49,000	0.9
	5,862,000	100.0

* Basic data from *World Petroleum* (February, 1941).
** In addition to this, German synthetic production at the outset of the war is understood to have been about 65,000 barrels per day, equivalent to 1.3 per cent of world production.

While the preponderance of American, British, and Dutch control of crude production is generally known, I think many, even in the industry, will be surprised to note the tremendous discrepancy between our 63 per cent of world production and the Axis total of 0.7 of 1 per cent. Our own 63 per cent figure is undoubtedly closely related to the fact that we have 65 per cent of the world's motor cars. Outside of Roumania, European production of petroleum is negligible and even including Roumania the crude-oil production of continental Europe, west of Russia, is only about 25 per cent of its normal peacetime consumption.

While we hear frequent references to the oil wells of Germany, Poland, Hungary, and Albania, the total production of all these countries in 1940 was only about 35,000 barrels per day, or about ½ of 1 per cent of world production. Roumania accounts for about 2 per cent of world production, which emphasizes the great importance to the Axis of control of this supply. Without the steady increase in imports to Germany from Roumania during the last half of last year their shortage would probably have been serious by this time. How-

ever, as I shall point out, even control of Roumania by no means assures that most of its oil can readily be made available to the German armed forces, because serious transportation bottlenecks stand in the way.

It is true that Germany has been making steady progress during recent years as a producer of crude and has, as claimed, trebled their production since 1933, but the cold figures indicate that this increase is from a meager 5,000 barrels per day in 1933 to about 15,000 barrels per day in 1940, or $\frac{1}{4}$ of 1 per cent of total world production!

If comparable figures were available as to proven underground reserves of crude the comparison would be even less favorable to the Axis powers, because they, and Russia as well, have been drawing on their own reserves about as rapidly as possible, whereas this country, South America, and the Near East, all have tremendous known reserves which have only begun to be tapped.

The foregoing figures show more clearly than words why petroleum supplies for the war are a matter of such vital national concern to the Axis powers, while our own military needs can be taken care of by our industry with so little difficulty.

We must not suppose, however, that Germany entered the war with less than $\frac{1}{2}$ of 1 per cent of the world's petroleum supply under her control without having several means in sight to augment her supply. Whatever we may say of Germany, she certainly does not lack foresight and the ability to plan ahead. She would never have dared to enter the war without those amazing achievements of technical and engineering skill, her synthetic-oil plants which make oil from coal and lignite by hydrogenation, and from coke by the Fischer-Tropsch synthesis. While the capital investment required was staggering, and operating costs are many times those involved in producing gasoline from crude, these processes were indispensable to filling the most serious gap in the German war requirements, and Germany concentrated on their construction before and during at least the first year of the war.

But let us analyze Germany's supply and demand situation in somewhat more detail. Pre-war requirements of Germany and France were each about 150,000 barrels per day, and about 75 per cent of France's requirements were in the territory presently occupied by Germany. Italy used 60,000 barrels per day, and the other occupied territory of Western Europe (not including any of the Balkan states) brought the total pre-war consumption of this area to about 430,000 barrels per day. Under pre-war conditions over 80 per cent of this oil came into Western Europe by tanker. This figure will serve as a stand-

ard against which to measure the available sources of supply. Of course this does not include any purely wartime demand.

As against this demand Germany has several different resources which I shall discuss separately. It must be understood, of course, that the figures from this point on are considerably less accurate than those previously discussed; nevertheless, various sources of information are in rather good agreement, except as I shall indicate.

1. CONTROLLED CRUDE PRODUCTION IN WESTERN EUROPE

The total 1940 crude production of Germany, Hungary, Austria, Alsace, and Albania, that is, the territory directly controlled by the Axis powers, appears to have been practically the same as in 1939, namely, about 25,000 barrels per day. These wells were widely scattered and, outside of Albania, were probably little affected by bombing or other war hazards; while efforts have doubtless been made to increase production by additional drilling, most of the fields were in their declining phase and the figure of 25,000 barrels per day from these sources can not be far wrong for 1940 and probably 1941.

2. SYNTHETIC-OIL AND GASOLINE PRODUCTION

Total synthetic-oil and gasoline production (including benzol from coke ovens to the extent that same was available for motor fuel) was between 60,000 and 70,000 barrels per day at the outbreak of the war. About 70 per cent of this was made by the hydrogenation process charging mainly lignite, plus some coal and some coal tar. This process makes good gasoline and most of the plants can be operated in such a way as to make fairly good aviation gasoline, though this reduces their capacity. This aviation gasoline can be leaded up to about 90 octane, which leaves it seriously inferior to the 100-octane quality which this country can supply.

The Fischer-Tropsch process was responsible for somewhat more than half of the remaining synthetic product. This process starts from coke and makes very inferior gasoline, but good Diesel fuel and some wax. Both the wax and the gas from this process can be used as the starting point for the synthesis of lubricating oils, but this process is difficult and no substantial amount of capacity appears to have been installed at last report.

Coke ovens in Germany produce substantial quantities of coal tar, and the benzol obtained therefrom is a much desired constituent of ordinary and aviation fuels, to the extent that it is available.

While alcohol was used in a small way before the war, it was already on the decline in 1938 and 1939 and probably is a negligible

factor to-day as its production in Germany requires the use of foodstuffs.

While the figure of 65,000 barrels per day must be very close to correct for the production of synthetic substitutes at the outbreak of the war, developments in that field since 1939 are increasingly difficult to estimate. Plants which were at that time under construction would bring the total capacity to-day (including the benzol) to around 100,000 barrels per day, and a few more plants may have been built without general knowledge. As against this, the daily newspaper reports bear witness to the fact that synthetic-oil plants and oil storage facilities are the favorite objectives of British bombing attacks. Up to the first of this year about 500 bombing attacks of greater or less severity had oil refineries, synthetic-oil plants, or oil storage as their objective. The British Ministry of Economic Warfare announced late last year that 90 per cent of Germany's synthetic-oil plants had been visited by bombing attacks. They added that while most of the targets had been heavily hit, synthetic production was continuing at a reduced rate.

While those familiar with the spectacular character of even a small oil fire will tend to discount even the most honest reports by aviators of great fires which were observed, considerable damage must have been done. However, it must be recalled that intensive bombing attacks on these objectives have been carried out only during the last 6 months of the 18 months of war. While these high-pressure plants with much complicated piping carrying inflammable products would seem to constitute ideal bombing targets, the fact that they do operate under such high pressure means that the principal parts have to be made of something like armor plate, and either a lucky hit at a vulnerable spot, or a direct hit by a large bomb would be necessary to cause any serious damage requiring a long time to repair or replace. On the whole, if England's bombing has kept Germany's total synthetic production down to 70,000 barrels per day I should consider it was remarkable, and 80,000 barrels per day present effective capacity would seem to me a better guess—though a guess it admittedly is.

3. IMPORTS FROM ROUMANIA

Roumania's production of crude has steadily declined from 1936 to date, due mainly to the gradual exhaustion of the older fields and failure to make new discoveries of importance. The rate of production at the end of 1940 was about 20 per cent less than in 1939 and more than 40 per cent lower than in 1936. The decline seems to have been largely due to increasing State control and the threat of war, both of

which acted to discourage wildcatting and new development. Only seven wildcat wells were completed in 1939. While Roumanian production averaged about 125,000 barrels per day for the first nine months of the year, the latest reports indicate that it dropped to 100,000 barrels per day near the end of the year.

Since Roumania consumes only about 40,000 barrels per day, it would seem that Germany had almost at her back door and now under her control a very large and convenient source of oil. However, the matter of getting this oil into Germany is by no means so simple as might appear. Before the war about 75 per cent of Roumania's exports were shipped out by sea, and only about 27,000 barrels per day went by rail and Danube barges, of which around two-thirds went into Austria, Hungary, and eastern Germany. However, this amount represented about the capacity of the barge fleet and the available tank cars. Roumania contracted to supply Germany with about 30,000 barrels per day during 1940, but up to July it had shipped to Germany only about 20,000 barrels per day. These reduced shipments were probably due to the longer average haul (it is about 1,800 miles to Western Germany), partly to an unusually severe winter, and partly to a mysterious shortage of barges and other transportation difficulties, which probably had considerable to do with the penetration of Roumania last summer and its seizure last fall. Even this did not solve all transportation problems, and the best evidence indicates that total exports to Germany plus Italy averaged slightly under 30,000 barrels per day for the year 1940. I believe this lack of outlet, rather than the earthquake, is the principal reason for the curtailment of Roumanian output during the last quarter of last year.

Naturally, Germany is far from satisfied with this state of affairs. In December, it was announced that a contract has been signed for the delivery to Germany during 1941 of a total of 3 million tons of oil, or about 60,000 barrels per day. Such a movement would appear to be practically impossible without greatly increasing transportation facilities, but it has been reported definitely that a 225-mile pipe line is being built from the principal oil fields near Ploesti to a point just west of the Iron Gate. This was supposed to be completed by around April 1st, but it would seem almost impossible for Germany to accomplish any such feat under winter conditions.

This line will obviate the difficulty of moving barges through the rapids and the narrows in the Iron Gates and will substantially increase the amount of hauling which can be done with a given number of barges. The rail line from the oil fields to Bucharest is also said to be in process of being converted to double track.

In December, General Antonescu decreed the seizure by the State of all oil properties, pipe lines, barges, *et cetera,* in order to marshall the country's petroleum resources. Even with these supplies, however, it may be that the difficulties of transferring adequate oil supplies to Germany's mechanized forces in Western Europe have been a factor in Hitler's decision to transfer a substantial part of these forces to Roumania, where they can operate with oil supplies close behind them. It seems to be a sort of modern version of Mahomet and the mountain.

Germany's problem of getting oil by tank car over the long route from Roumania and Russia is undoubtedly made more difficult by their need for tank cars to transfer all sorts of oil products from the interior of Germany to the invasion ports and air fields, frequently by long and inconvenient routes. She undoubtedly did capture a good many tank cars during the Blitzkrieg, but most of them are probably needed to maintain her abnormally long supply lines from her synthetic plants to the points where her army, navy, and air forces are now operating. Also, a large number of tank cars have undoubtedly had to be transferred to the similarly long haul from Roumania into Italy as Italy's stocks approach exhaustion.

On the whole, if the Axis is able to import an average total of 50,000 barrels of oil per day from Roumania into Germany and Italy during 1941, it will have done an excellent job. From England's viewpoint it would appear that attacks on communications from Roumania, rather than on Roumanian oil wells and refineries, would probably be the most productive of prompt and valuable results.

4. IMPORTS FROM RUSSIA

Before analyzing the probable contribution of Russia to Germany's supply, it may be of interest to take a long view of what Russia has been able to accomplish as the result of her much advertised 5-year plans and rigid State control of the whole industry. I can well remember a discussion among some oil men in 1932 when Russia was exporting about 120,000 barrels of oil per day, and her program called for rapid expansion of all petroleum facilities, so that companies with European markets feared there would be little left for the Western Hemisphere to supply. State-controlled exploration programs covered wide areas, and much refinery and drilling equipment was imported. What happened? Russia has made a gradual increase in her total production, but her percentage of the total world supply has been declining steadily and her exportable surplus dropped from 120,000 barrels per day in 1932 to less than 20,000 barrels per day in 1938—and the year of our Lord 1941 finds mighty Russia actually *importing* oil from

both the United States and Roumania. Also she has recently found it necessary to start rationing gasoline to civilians. Thus, State planning and expensive exploration programs bow again to the wildcatter—that outstanding example of free enterprise who, in spite of losing money on the average, is spurred on by our "hope-of-profit" system to keep our nation preëminent in petroleum.

Again, Russian oil supplies to Germany have been widely advertised, but either Russia's inability to spare any oil, or the difficult transportation problems involved, have kept imports to an almost negligible figure. The direct rail haul from the Baku region to Western Germany is about 2,500 miles and the difference in railroad gage necessitates a transfer en route. Also, Russia, as well as Germany, has been short of tank cars. The more efficient route by pipe line to Batum on the Black Sea, tanker to Constanza, and barge or tank car through Roumania merely serves to congest the shorter route from Roumania's own fields.

Germany probably has gotten the lion's share of the oil produced in the Russian-occupied part of Poland, amounting to around 8,000 barrels per day, and some heavy lubricating oils of which Germany is particularly in need, and which neither her synthetic plants nor Roumania can supply.

While admittedly based more on the logic of the situation than on any actual figures, my guess would be that Germany's average imports from Russia since the war began have been around 15,000 barrels per day. Even this would be about five times Germany's pre-war imports from Russia. A recent newspaper report from Russia said exports to Germany were being cut off entirely, and while her definitely announced agreement to import oil, from Roumania, and her rationing of gasoline would lend credence to this, it can scarcely be relied upon as definite.

5. IMPRACTICABILITY OF GETTING SUPPLIES FROM NEAR EAST

Numerous columnists and arm-chair strategists have in recent months expressed the opinion that Germany's Balkan adventures were largely stimulated by her desire to get access to the oil fields of the Near East, in order to augment her own supplies. From what I have shown as to transportation bottlenecks in getting oil from the much nearer fields of Roumania and Russia the unlikelihood of any such theory must be apparent. Even if these fields could be captured in usable condition, which seems highly improbable, they would be of little value for getting oil into Germany unless she had effective control of the Mediterranean. Of course she doubtless would like to cut off

British supplies even if she could not make much use of them herself.

SUMMARY OF AXIS' SUPPLY POSITION

To summarize the Axis situation, it would appear that during 1940 the total of Axis imports plus domestic and synthetic production of petroleum and its products (not including imports by Italy before she entered the war or stocks seized during the Blitzkrieg) probably averaged slightly over 150,000 barrels per day, or about 35 per cent of the peacetime requirements of Axis-occupied territory (not including Roumania). In other words, their supplies have been cut to about one-third at a time when their total requirements probably have been nearly doubled, if the military, industrial, agricultural, and civil needs were really to be taken care of. Of course, the answer has been the practical elimination of all civilian consumption throughout the occupied territory, and very sharp curtailment of industrial and agricultural consumption.

There is every evidence that Italy's reserve supplies are practically exhausted, and that her collapse in Africa has been speeded by lack of gasoline. As a matter of fact, Italy's entrance into the war has proved to be a severe blow to the Axis petroleum-supply situation, because before her entry she was able to pass along some of her heavy imports to Germany, whereas Germany now has the problem of diverting part of her transportation facilities and oil supplies to try to keep Italy in the fight. Seizure of Norway and the Low Countries probably had a somewhat similar long-term effect on oil supplies, in addition to delivering much needed tanker capacity to British control. To illustrate this, Germany's neutral neighbors imported more than twice their normal requirements of lubricating oils between September, 1939, and February, 1940, when the British Ministry of Economic Warfare began to clamp down on such shipments.

The answer to the common question "Is Germany short of oil?" must be "Yes," so far as the broad picture is concerned. Even in Germany such sharp curtailment of civilian consumption must mean much loss in efficiency. Her fine new roads, which Hitler built to relieve his railroads in the event of war, are contributing little to her wartime economy, as everything possible must be hauled by rail to save gasoline. On the other hand, it does appear that both the army and the Gestapo have adequate supplies of gasoline for all their operations and day-to-day use, and I do not believe that any purely military operation has thus far suffered from a lack of over-all gasoline supplies. As a matter of fact, less than 100,000 barrels per day of petroleum products properly distributed should keep even the German army

going its present pace more or less indefinitely, though during the height of the Blitzkrieg the consumption was probably around 400,000 barrels per day. Unfortunately, her boast that she was able to more than finance this effort by the oil stocks which she was able to capture is probably correct. However, the continued extremely short rations of industry and agriculture are bound to have adverse effects on her whole economy.

The one petroleum product of which Germany's shortage appears to be the most serious is heavy lubricating oil. Almost all elevators have been shut down due to this lack. Extraction plants have been installed in many industrial plants to recover oil from rags and waste used around machinery. Vegetable oils have been pressed into service with frequently unsatisfactory results. Oil from downed planes has been reported to show evidence of having been used well beyond what we would consider safe practice.

Wax and asphalt are two other products of which the Axis appears to have inadequate supplies.

RESERVE STOCKS IN GERMANY AT START OF WAR

The greatest uncertainty about the whole German picture lies in the amount of stocks with which she started the war, and what has happened to them since. While stocks were doubtless large, I can not give credence to reports that she had 2 years' normal supply, or something like 100 million barrels, tucked away. I feel sure she had neither the time, the money, nor the facilities to store any such large quantity. Also, if she had any such stocks, she would not have run short of the vitally necessary product of lubricating oil before the war was a year old. She may well have accumulated 30 million or possibly 40 million barrels of stocks and figured that this would take care of the deficiency between her minimum requirements and her supplies for a two-year period, during which she figured she could either win the war, build enough more synthetic plants to carry her, or seize Roumania. However, she could have hardly foreseen the necessity of having to supply at least some oil to almost all of Europe for a long period, without having won the war. Whatever her stocks were, it seems fairly certain that they have been drawn upon to a substantial extent, and that her whole oil supply situation is a matter of serious concern to her. Bombing attacks on oil-storage centers also seem to have been particularly successful, as might be expected.

DIFFICULTIES INVOLVED IN ALL-OUT AIR ATTACKS ON BRITAIN

This analysis still seems to have one very pertinent question un-

answered. If Germany has, as would appear to be the case, plenty of gasoline for her army, why has she never made more effective use of her 20,000 to 25,000 first-line planes in continued all-out attacks on England, and why do "breathing spaces" of weeks generally precede and follow such heavy attacks as she has made, even with only 2,000 planes? While fuel shortage might seem to be a logical explanation of this, as I have indicated, it does not appear that there can be any serious shortage of aviation gasoline in Germany as a whole. I believe a more logical explanation will appear when we analyze the supply and transportation problems involved in any such all-out attacks.

Let us assume, for example, that Germany should decide to make an attack against England which would utilize 8,000 bombers and 4,000 pursuit planes, representing half of her total force, and let us assume further that she had some 200 suitable airports available along the invasion coast of Western France around to Norway. Preparing for such an attack would mean in the first place that provisions would have to be made for storing, maintaining, fueling, and taking on and off about 60 planes at each airport, in spite of probable attacks by opposing bombers. To put such a fleet of 12,000 planes into the air for only 5 hours per day would require about 7 million gallons of gasoline and probably something like 18,000 tons of bombs per day.

With the limited transportation facilities available, bringing up enough such material, plus mechanics, spare parts, *et cetera*, for a week's attack would undoubtedly require several weeks and the material once brought in would from then on be subject to loss by bombing. It is not strange that Germany was not able to assemble enough such supplies to make an effective all-out attack on England last fall, and even with a long winter preparation, including building and camouflage of new air fields and hangars, building underground storage facilities, *et cetera*, it would be an almost superhuman task to bring a force of 12,000 airplanes to bear against England for even a few hours, to say nothing of continuing such an attack for the several days which would probably be the necessary preparation for invasion. Germany is reported to have several "flying tankers" designed to supply fuel to remote airports, but the cost of gasoline delivered in this way, when she is already short of gasoline, must be almost prohibitive.

Thus, while there is probably no all-over shortage of gasoline for army needs, the difficulty of transporting such quantities of fuel to inaccessible locations in a country which does not have the background of large and efficient petroleum transportation facilities is almost insuperable. It could certainly account for the very limited scope of the attacks which have thus far been made on Britain, and even with all

winter to prepare, it seems doubtful if it can be satisfactorily solved by Germany.

OUTLOOK FOR FUTURE

Whether or not Germany's oil shortage will seriously hamper her this summer seems difficult to predict, but there are three ways in which the oil situation is working against her for the long pull. These are:

1. Italy, due only partly to lack of oil, will be more of a liability than an asset to Hitler from now on.

2. Germany's long-pull oil outlook must be discouraging to her, and require considerable diversion of attention and energy to getting more oil supplies which she would prefer to use in other ways. Also, the shortage must interfere increasingly with both her industrial and agricultural production and eventually her military operations.

3. If and when England can achieve sufficient air superiority to permit long-range and heavy daylight attacks on German synthetic plants and transportation facilities, she will be striking at such a vital spot that actual invasion might never be necessary in order for England to win the war.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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FIFTH DIMENSION IN THE OIL INDUSTRY[1]

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We are all seekers after knowledge. An engineering friend of mine told me about his wife who had asked him to explain to her what was the Fourth Dimension. He had spent a half hour trying, when she spoke up and said: "Now that I understand that perfectly, what are the other three?" As the Fourth Dimension is so well understood, I think it is time to go deeper into the realms of mathematics, and to give you a definition of the "Fifth Dimension."

A "Fifth Dimension" is something "what ain't"—"yet is"; and the Petroleum Geologist was and is its first and chief exponent.

I am leaving a proper definition of my subject to you gentlemen, who are its creator, and who have demonstrated that we have a Fifth Dimension in the Oil Industry.

There is a certain story in the Bible which I have thought ought to be read at all meetings of the American Association of Petroleum Geologists—the story of Elijah. If you gentlemen of the geological profession had read your Bibles as devotedly as I have read mine, you would long since have chosen Elijah as the patron saint of your organization, and from the fact that you haven't accorded him proper recognition I can only assume that you have never heard his story. That doesn't surprise me. In my own association with petroleum geologists, I have long ago become convinced that a larger knowledge of the Bible's teachings would be good for them. So I am going to tell you the story of Elijah. If you don't believe me I refer you to the 16th and 17th Chapters of the First Book of Kings.

In the time of Elijah, a certain Ahab was King of Israel. He was an exceedingly bad actor, and Elijah, having denounced him, was sent away into the wilderness, where the ravens brought him food morning and night and he drank of a brook. But a drought fell on the land and the brook became a "dry hole." Thereupon Elijah, under instructions from Jehovah, went to a place called Zarephata, where he found a widow whom he asked for food and drink. The widow had only a handful of meal in a barrel, and a little oil in a cruse; but from it she made him a cake; and behold! thereafter there was always ample supply of meal in the barrel and oil in the cruse, so that the Scripture says: "And she, and he, and her house, did eat many days. And the barrel of meal wasted not, neither did the cruse of oil fail."

[1] Read before the Association at Houston, April 3, 1941.

[2] Vice-president, Sun Oil Company, 1608 Walnut Street.

I don't think it is necessary for me to point out the parallel between Elijah's miracle with the cruse of oil, and the miracle which you geologists have performed with our national oil supply. You've kept us in oil, even though I'm bound to say you've made a good many guesses that sadly lacked inspiration from on high. For instance, I remember that back in 1915 the U. S. Geological Survey made a study of the country's underground petroleum resources and found 7,600,000,000 barrels, plus 75,000,000 barrels which it labeled as "prospective." That was a good deal of oil, but as we were taking it out of the ground pretty fast it seemed desirable to have you gentlemen provide us some more. So in 1921 the U. S. Geological Survey tried again. It enlisted a group of your most eminent members to make another survey. They did, and accommodatingly reported that there were 9,150,000,000 barrels of oil in the ground, plus 130,000,000 "prospective." That was a comforting increase, but, as consumption was going up very fast, the oil industry felt it couldn't get along safely with only 9,150,000,000 barrels plus 130,000,000 "prospective." So you miracle workers were again appealed to, and again you boosted the supply, as you have been doing ever since from time to time. To make a long story short, since you promised us 9,150,000,000 barrels in 1921, we have produced over 14,000,000,000; and now you assure us that we have known reserves of 20,000,000,000 barrels. That is good work, boys; it's plain that you've got possession of the miraculous cruse, and I hope henceforward you will follow the advice of Mr. Pickwick and "bevare of the vidders."

Not only are you a progressive profession, but I have especially admired your versatility. There is probably not an executive here who has not repeatedly had his structures changed overnight for him by his geologists. The fact is that you can't just tie down a structure with a lead pencil.

The oil industry, and your geological profession in its relationship to that industry, are both getting unwonted attention just now because of the supreme importance of oil in a world at war. More than almost any other natural resource, the supplies and distribution of oil are at this moment affecting the destiny of nations, the course of history. I think it is not too much to say that our very hopes for the future of civilization largely depend on our success in developing, producing, and manufacturing a product that is difficult to find, difficult to produce, and difficult to reduce to its best values for use. Yet I know of no industry that has met the demand of an ever-increasing comsumption and the need for constantly better quality of product, as has the oil industry. So I am going to speak briefly of the military

and civic need for our product, and of our provisions for meeting these needs. The subject naturally falls into four divisions: first, the adequacy of supplies; second, of transportation; third, of manufacturing facilities; and finally, the general efficiency of the industry and its record as an employer.

If over the last twenty years we had been looking forward to the war emergency which now confronts us, we could hardly have planned to meet that emergency with more confidence than we now feel. When we entered the first World War there was ground for some apprehension about petroleum supplies. At that time this country was producing about 900,000 barrels daily; now it is producing four times that much. At that time we were using it as fast as we could get it out of the ground; to-day we have a constant struggle to keep production from outrunning demand. By the mere opening of valves we could overnight add 30 per cent to present production. I am advised that this would take care of any extraordinary requirements due to war conditions, in addition to providing for probable ordinary public needs, for a period of two years. And if after the two years had expired there should still be need for continuing production at this increased rate, I have every reason to believe that it can and will be done, and done without violating reasonable conservation practice. The whole history of the industry justifies the expectation of continually increasing production when it is needed. There are hundreds, possibly thousands, of locations for wells yet to be drilled in known producing areas, while new discoveries are also to be expected from many known but as yet undeveloped structures. In addition, the discovery of new structures can be confidently anticipated.

In 1917 reserves in the ground were estimated at 4,000,000,000 to 5,000,000,000 barrels. To-day, known reserves, largely developed by the drill, are about 20,000,000,000. These reserves are for the greater part still in the ground, which is most fortunate; that is the best possible place for them, both to preserve quality and to protect against any kind of attack. A thousand, yes 5,000, wells could be destroyed, if that were possible, without affecting a single barrel of our reserves, and without materially affecting available supplies or our ability to meet all requirements.

Present policies and methods look to crude-oil production in such manner that the greatest ultimate recovery will be had. That is the true program of effective conservation, and far be it from me to advocate any departure from such a policy. Nevertheless, in an emergency such as war might present, some producing regulations might have to be temporarily suspended or modified in order to meet all demands.

But even in such an exigency, present methods are best adapted to meet requirements with minimum violation of best producing practices, and most surely to produce the best results.

Let me add in conclusion of my observations on this subject of reserves, that I trust you Petroleum Geologists, discoverers of the great truth that sometimes "what ain't"—"yet is," will give me credit for an adequate demonstration of my super-Einsteinean theory that there is a "Fifth Dimension."

Now, a word about transportation. The oil industry I believe is the only one that has developed its own complete and unique transportation system. It is the cheapest transportation ever devised, and its economic importance, I think, is fully recognized by but few people in the industry, and by almost nobody outside of it. This is most unfortunate; there is need, pressing need, for a thorough study and general understanding of the economics of transportation as a factor in this industry.

Petroleum, like gold, is where you find it; and you usually find it in out-of-the-way places. I venture that if petroleum had to be moved by conventional transportation facilities, from the oil fields to the refinery, and, if its products had to be moved to market by those same facilities—the cost would be so great that a major share of the world's oil fields would never have been developed. Even as it is, something like 40 per cent of the cost of the gasoline you put into your car at the filling station represents transportation. Without the pipe-line, the tank-ship, tank-car, and tank-truck transportation system that the industry has built up, that additional cost would have been multiplied several times, to a point where the price when it reaches the consumer would be so great that few could afford to buy it. That, of course, would mean that all the wide range of other industries that are dependent on cheap petroleum and petroleum products could never have been developed at all. We would have thousands of motor cars where we now have millions; we would have hundreds of miles of modern highways, where we now have thousands of miles.

Our pipe lines, tank ships, tank cars, and tank trucks round out a complete system to handle the raw materials and the products of this industry, a system that is not fitted to serve any other industry or any other transportation requirement. Consider the pipe lines. They serve as outlets to particular oil fields, or as feeders to particular refining plants, or as both. With the development of oil fields in new and remote areas, and the construction of new refineries, there has thus been built up a great transportation system that is the life-line of the industry. It is of importance alike to the producers from hundreds of

thousands of wells, to the refiners who have invested millions in the faith that the pipe lines would bring them oil, and to the millions of consumers. The refinery is so dependent on a continuous supply of crude that no course is left to it but to finance and build its own pipe line and to keep on building more as its needs require and as the sources of crude supply change. The pipe line is indispensable to the refinery; the pipe line's ability to supply the needed crude is so dependent on its extension whenever and wherever the oil is available that the pipe line has been properly considered a refinery facility. The larger the refinery, the more urgent its need for a never failing supply of crude. This can be assured only through the operation and control of the constantly expanding pipe-line system. That system, again, assures to the thousands of independent producers a constant outlet for their oil and a competitive market for it. Being assured of this outlet and this market, the wildcatter, large or small, on whom at last we must depend for maintenance of our supplies, can carry on his operations with complete confidence.

On this basis we have built up in this country a pipe-line system that reaches to every oil field, however remote, and connects these fields with refining and consuming centers all over the land; while by way of tank ships we reach the centers of refining and consumption all over the world. In any emergency these facilities can be expanded quickly and at comparatively small expense. Pipe-line capacities can be increased cheaply by looping lines or putting in additional pumping stations, or both. This can be done when and where the need requires, and to the extent required by the emergency, and capacity increased only if the need is developed. Most of the necessary tankage has already been built along the trunk lines. Telegraph lines, rights-of-way and many other necessary adjuncts already exist.

Popular ignorance about the industry's transportation system is reflected in a recent newspaper item suggesting the building of a pipe line of large capacity from the Texas-Louisiana oil fields to some place on the north Atlantic coast, perhaps as far north as Portsmouth, New Hampshire. This is just one of the multitudinous projects inspired by hysteria about national defense. There is no need for such a line, which would merely be a duplication of facilities already in existence and which can be easily expanded. It would present an enormous and unnecessary demand on our iron and steel industries, and would spell the waste of a vast amount of money that ought to be invested in practical and necessary projects. It is highly important that ill considered proposals of this kind be carefully analyzed in relation to facilities already in existence and adequate to render all

the service required. Both as to the supply of oil and as to its transportation, the industry is in far better shape than ever before and if left to handle its problems with a minimum of Government interference it can guarantee good and satisfactory performance.

I shall not attempt here to analyze the refining situation. Refining capacity to meet any emergency demand already exists. True, some of it is termed obsolete or obsolescent, but in emergency it would serve its purpose more promptly and at far less expense than a big program of new construction. Nor do I think we need be concerned because so many of these plants are located on or near the seaboard. Certainly the Gulf Coast refineries, at least, will be well protected by the new system of island defenses for which we have recently acquired concessions from Great Britain. When this chain of air and naval bases is completed, it will in effect convert the Gulf and Caribbean areas into inland seas, and refineries on the Gulf will be thoroughly protected. We are building new munition plants, aircraft factories, machinery and equipment establishments within these same seaboard zones, where they are no less vulnerable to enemy attack than are the oil refineries. Moreover there are sound reasons for the location of a large proportion of our refining capacity along the coast. Transportation is better there, and products are needed there; and finally, even if refined in the interior, the products would have to be stored in great quantities along the coast—just as vulnerable to attack as refineries would be. Greater protection for all vital industries will be provided in the coastal areas.

Turning to the matter of labor supply and labor relations, we recall that this industry has never had anything like a major strike. And there is a reason. It has mobilized an exceptionally fine type of loyal employees, including the best scientists and technologists, mechanics, and skilled labor. It has held them, because it has deserved them. During a decade of depression this industry has known no unemployment, while the level of wages has been raised and working hours have been reduced. As regards its labor relations, Dr. Isador Lubin, Commissioner of the Bureau of Labor Statistics, declared during the T.N.E.C. inquiry that for many years he had held up the oil industry as a model in all these regards.

If it is left unhampered by governmental interference, the oil industry can give full assurance that it will meet every requirement. It needs no regulation. Rather, I firmly believe that government regulation of an industry of this kind, and most industries, can only produce inefficiency. That was the experience in the last war. In one industry with which I have some familiarity the Government's attempt to

control labor and operating conditions caused a loss of 30 per cent in efficiency. Any attempt to centralize control of the oil industry, or of industry in general, more than is absolutely necessary, is just creating new bottlenecks; and bottlenecks which retard production are already too much in evidence. A well organized industry such as ours, with experience, and with a record of accomplishment such as no other industry can boast, can and will function more efficiently as a free industry than if it is subjected to new and burdensome regulations. There are already plenty of laws and rules to guarantee protection of labor under any conceivable conditions. These laws and rules should be obeyed, and in the oil industry they are being obeyed, and more; the oil industry has always gone far beyond any legal requirement in maintaining attractive employment conditions. The real danger, the real menace of inefficiency, lies in bureaucratic domination by inexperienced people; in the multiplicity of reports that are required, the imposition of impractical conditions, the weaving of red tape with no useful purpose but at heavy cost. Loyalty to an industry or to a job can easily be destroyed when it becomes apparent that those responsible for the output of the industry or the job have no effective control over the organization.

There should be no bottlenecks in the oil industry to interfere with production adequate to meet requirements of to-day—which are the greatest in our history—plus any conceivable emergency increase, for the next two years. I am told that during that time no increase for emergency requirements of over 10 or 15 per cent can be expected; but, if and when additional supplies are required, whether within two years or thereafter, the oil industry is so flexible, so easily adaptable to any program of expansion, that all requirements can and will be met. Our known reserves are the greatest in our history; our whole set-up of production, transportation, and manufacturing can be expanded with practically no disturbance to the industry. The only bottlenecks that need be feared would be such as would result from the sort of interferences I have suggested—well meant, but impracticable; interferences that would prevent the industry from quickly and efficiently responding to demands. Competition in the industry is the most vigorous in its history; prices are low; profits are low; profiteering can not honestly be charged, because it does not exist. The industry has done an efficient job; why mess it up? It will continue to do its part with a patriotism not surpassed by any other industry or any group; but it should be permitted to do its difficult job in the manner best known to it, and which will produce results.

There need be no bottlenecks in the oil industry such as exist in the

manufacture of those types of equipment for which tools and supplies have to be specially provided. We have full confidence that every requirement of industry will be met, through the efficient functioning of the National Defense Commission, composed as it is of men experienced in dealing with the varied problems of large-scale production.

In conclusion, let me recall what I said a little bit ago about the miraculous achievements of the petroleum geologists in keeping our supplies of oil always ahead of requirements. No matter how much we have used, or how fast consumption is increased, they have always furnished us with more than enough. In the bright lexicon of the petroleum geologists the word "deficit" doesn't appear. So as a last observation I am going to suggest that the Association of Petroleum Geologists appoint a committee of its experts to consult with the Bureau of the Budget at Washington. What that Bureau needs nowadays is the advice and counsel of an organization like your own, which has always specialized in surpluses rather than in deficits.

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NATURAL GAS WITH REGARD TO ITS PLACE IN NATIONAL DEFENSE[1]

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It's a pleasure for me to have the opportunity of meeting with you to-day.

I am sure you have all read a great deal, and many of you no doubt have heard numerous talks, about the defense preparations of our country. This subject has already been discussed so thoroughly in general that there may be little more I can tell you in regard to its broader phase.

However, I would like to give you a few of my thoughts on the place of natural gas in our defense program and the part I believe it will play in the future peacetime operations of our country.

I think we all agree that the oil and natural-gas industry, as it exists to-day, is playing an important part in our national defense program. The part it will play in the future, throughout the duration of our present world conflict, and more particularly in the period after this conflict is over, is of paramount importance to every one of you here to-day.

Most of you will recall that we had a very different situation in the days of 1917–18 from that of to-day. For instance, we had no trained armies or trained officers. It was necessary to establish, at great cost, our officers' training camps to train officers first so that they in turn could train others. Our industrial production was not organized and centralized as it is to-day. Our known oil reserves were far below what they are to-day. Shipping and other means of transportation, our communications systems, and factories of all types, could not assume the burdens put upon them without complete reorganization and expansion.

So the situation during World War I was far different from that of to-day. At that time it was trained man-power, weapons, and food. To-day these things are necessary, yes—but most important is industrial production. To-day high-speed airplanes, tanks, and the many other machines of war are of greater importance. The many requirements of mechanized warfare have made industry America's first line of defense, and the oil and gas industry essential to this program.

Since the passage of the lend-lease bill and the adoption of a gigantic program to aid Great Britain in her fight against the totali-

[1] Read before the Association at Houston, April 3, 1941.

[2] President, United Gas Pipe Line Company and Union Producing Company.

tarian powers, we are realizing the necessity of industrial production on a far greater scale than was considered even a few months ago. With these new developments have come increased demands for more and faster industrial production.

I would like to mention briefly the part the natural-gas industry is now playing and is prepared to play in meeting these increased requirements.

In 1917, when industry was called upon to do its part in the World War, the total natural-gas production in the United States was approximately 800 billion cubic feet. In 1939, which is the latest year for which figures are available, natural-gas production in the United States had increased to approximately 2½ trillion cubic feet, or more than three times the amount produced in any year during the first World War.

While these figures are impressive they still don't tell the whole story. In 1917 and 1918 the use of natural gas was limited almost entirely to small areas, or markets adjacent to the source of supply. In the 22-year period between our two world conflicts we have seen the development of high-pressure pipe by the steel and tubular-goods industry. This opened up a new world and afforded a transmission method by which natural gas could be taken from fields and carried economically to manufacturing and industrial centers hundreds of miles away.

This development of long-distance transmission lines stimulated the discovery of new reserves, encouraged better regulation and helped the industry to expand on a sound basis. It was not until this expansion took place that such cities as Houston, to which natural gas was piped in 1926, could enjoy its benefits.

So we find that this industry that was in its infancy in the World War days of 1917–18 has now become a young giant, consisting of a network of more than 180,000 miles of pipe lines connected to more than 50,000 producing wells from which natural gas is transported safely underground to many of the principal industrial centers and communities of the nation.

Natural gas is meeting the increased fuel requirements of many industries and factories now engaged in manufacturing vital defense products and equipment. It supplies the heat for making much of the aluminum which is now used extensively in airplanes and other machines of war where strength and durability, with minimum weight, are major factors. It is used in the only antimony smelting plant in the United States, located at Laredo, Texas. Antimony, which is used in manufacturing medicinal agents and munitions, is one of the 10 mineral

commodities classified as strategic by the Army and Navy Munitions Board.

In the production of clothing and food products, in chemical plants, steel and lumber industries, ship-building plants, oil refineries, naval bases, air bases, and cantonments, all of which are vital in our defense program, natural gas is playing an important part.

I believe this brief review shows that the preparation made within the industry during the past quarter-century now bears fruit. The natural-gas industry is in a position to-day to meet the increased demands put upon it.

In my opinion much of the credit for this present preparedness, for the growth and development of this industry, is due the geologist and engineer.

Without the knowledge, efforts, and accomplishments of the men of your professions, part of which is the discovering and determining of gas reserves, this growth would not have been possible. It was not until the industry could be assured of adequate reserves that it could look to the future and develop on a sound basis. With this assurance large investments were made, long-distance transmission lines were built and gas was made available to communities and industrial plants not previously enjoying its benefits.

By the work of the geologist great strides have been made in recent years. It is through the coöperative work of the geologist and engineer that we can drill deeper and straighter holes, predict with reasonable accuracy the amount of reserves and the economical rate at which these reserves can be produced.

What can we expect in the future? The latest available figures show that the known natural-gas reserves in the United States, as of 1938, were estimated at 66 trillion cubic feet, which to me, under proper development, puts the industry in a fine position to meet all demands put upon it for national defense.

Also, through your efforts and experience we have made intelligent progress in spacing programs. While the cost of drilling either a gas or an oil well is approximately the same, to comparable depths, the spacing programs must necessarily be considered from entirely different angles. Oil can be stored above ground but gas must be produced only as needed. The demands for gas are fluctuating but there must always be a sufficient supply to meet peak deliveries. It therefore follows that in the development of gas reservoirs accurate detailed studies of reservoir conditions must be made in order that an adequate supply of gas can be maintained with a minimum number of wells.

In the past you have helped the natural-gas industry progress by

encouraging more and better coring which has improved our knowledge of subsurface formations. We are certainly drilling straighter holes than we were several years ago which gives us more accurate structure-mapping on producing formations than we had in the past. The collecting of facts in the field—the assembling, classification, and analysis of physical data by you—have assisted in laboratory research which has contributed much to the development of the oil and gas industry.

These are a few of the problems of the past which you have helped solve. However, as the demand for natural gas continues to increase and as the industry continues to develop there will be many new problems for the men of your professions.

I do not claim to be a prophet. None of us can be sure what the future will bring. We do know that after the first World War we had a greater industrial development and expansion than even the most optimistic business leaders thought possible.

What can we expect following our present conflict? Many of us believe now, just as many of us did twenty years ago, that we have reached a saturation point in new discoveries, improved methods of living and industrial expansion.

I, personally, believe that we will have greater opportunities for expansion after this conflict is ended than we had at the beginning of the reconstruction period following the first World War. My reason for this is not based on any statistics, but to-day there has been more physical destruction in the warring countries than we had in 1918 or ever felt could be possible. At the end of the conflict—and it will come to an end—Continental Europe and Great Britain will have to be rehabilitated, and we should come out of this conflict with at least an opportunity to use our factories and industries to furnish materials for that rehabilitation as well as to supply an additional amount of the world trade.

If this is true there is even a greater challenge for the geologist to-day, and everyone connected with the oil and gas industry, than ever before in our history. It seems to me that we have every reason to believe that not only the oil and gas industry, but our whole industrial structure as well, must meet this situation.

Many new uses are now being found for natural gas. It now contributes essential ingredients for motor fuels and in the manufacture of synthetic rubber and plastics, solvents, anti-gelling agents, and many other essential products.

In this connection the natural-gas industry is preparing to finance, under the leadership of a committee headed by a man right here in

Houston, Mr. Frank C. Smith, a research laboratory in connection with one of the important technical schools, looking for the further development of uses of natural gas, both in combustion and in chemical development.

While to-day we think nothing of the drilling of wells to 10,000 feet and even deeper, I believe that in the not too distant future as our search for additional reserves continues wells will be drilled to much greater depths. As wells are drilled to greater depths it will be increasingly necessary to secure the most economical production of hydrocarbons from these deeper reservoirs. This will not only require conserving and utilizing to the fullest extent the natural-gas energy but the most economic development program for a given field or horizon; and I predict that as we drill to deeper formations, and even in drilling at the present depths, economics will lead us to a unit development by fields rather than by drilling certain leases within a given field. This further challenges the technical branch of the industry.

Recycling operations, repressuring, and other means of conservation will probably be developed on a greater scale in the future. However, these developments must necessarily depend on the knowledge and data secured by the men of your profession. These practices are crude indeed compared with what probably will be developed in the future. Certainly proper spacing of both production and in-put wells in recycling operations is necessary for the most efficient recovery from a reservoir, thus avoiding the premature drying-up of the gas before the maximum economical recovery is produced. This brings us right at the present time face to face with the unit development previously mentioned.

We must not lose sight of the fact that many of the problems confronting us to-day in the rapid development of the oil and gas industry are in the meeting of the increased requirements of our defense program.

We should look upon these defense requirements as an emergency —a temporary period which we all hope and believe will be a thing of the past in the not too distant future. We must not come out of this emergency period with the oil and gas industry in a condition of chaos.

So while we are increasing production and expanding facilities to meet defense requirements, let us make our plans to fit in with the normal peacetime operations of the future. The oil and gas industry has expanded rapidly in the past. It will be through your intelligent

day-to-day work and planning that the industry will continue to expand—that we will be able not only to meet the increased demands during this emergency but be able quickly to adjust ourselves to peacetime operations.

This is a challenge to all industry and is indeed a challenge to our industry—a challenge to each and every one employed in our industry.

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THE PETROLEUM GEOLOGIST AND THE SECURITIES AND EXCHANGE COMMISSION[1]

SUMNER T. PIKE[2]
Washington, D. C.

I am both a Commissioner of the Securities and Exchange Commission and an associate of the American Association of Petroleum Geologists. It seems to me only natural that I should want to speak to you about the relationship of these two organizations. In doing so, I welcome the opportunity to lay before you some specific proposals for your consideration.

The SEC is a federal agency established by Congress to help the nation's investors. Under the Securities Act the SEC doesn't prevent the sale of bad stocks or bonds. Nor does it advise the investor what to buy. Our job is merely to have the full truth about a security disclosed to the investor so that he can make up his mind intelligently about his investment. These requirements are not large. You and I expect that the truth be revealed to us about the geological equipment we buy and use. If the truth is kept from us and we buy damaged equipment, we feel gypped. The same is true about the investor who buys sour securities that were misrepresented to him as blue chips.

Now I want to allay any possible fear that the SEC, being a federal government agency, is run by a lot of green-eyed monsters. The people who work at our shop are people like yourselves. Being public servants, their opportunity is to earn your friendliness by maintaining, as I believe that many of them are doing, an atmosphere of efficiency and coöperation. To do that it is necessary for them to be modest as well as efficient; to be open-minded instead of bureaucratic; and more important than anything, to be human in their relations. They, as well as I, must think of the public whom we serve as human individuals, hoping that, in return, you will recognize us not as distant and disagreeable policemen, not as symbols of irritation, but as a group of human beings possessing the usual quota of human shortcomings.

You may be wondering where the SEC fits in with petroleum geology. In one respect the oil and gas business isn't much different from other business enterprises. It takes money to obtain seismograph records, to construct derricks, to drill wells, to refine crude petroleum and to market the finished products. In raising money the oil operator often sells stocks, fractional undivided interests in leases, royalty interests, notes, or other securities to the public. At this point the oil

[1] Read before the Association at Houston, April 3, 1941.

[2] Commissioner, Securities and Exchange Commission.

operator finds that the Acts administered by the SEC require him to tell the complete truth about these securities.

It is customary for the petroleum geologist to make a report on the area which is about to be explored or exploited. And that is where you come in. If your report is going to be used to sell oil securities to the public a copy of it must be filed with us. Or if a geological expert helps prepare or certify a registration statement covering securities proposed to be sold, once again the geologist may come to know directly about the SEC.

These geological statements are matters of public, as well as private, concern. Geologists, therefore, must assume full responsibility for the preparation of sound reports. It is essential that petroleum geologists develop means of reporting, measuring, and interpreting the geological aspects of the oil business to the prospective investor in accordance with principles and standards which are definite, professional, and widely accepted. Such principles and standards can and should be promptly developed.

To my way of thinking, there are minimum standards whereby geological reports should be judged. The geologist should be in good standing and entitled to practice his profession in the place of his residence or principal place of business. He should meet those requirements of training and experience which are prescribed by local law. If he passes these basic tests, the geologist would ordinarily be entitled to represent himself as one whose profession gives authority to a statement made by him. In addition, however, the report should be based upon procedures and examinations followed and recognized by members of his profession as an adequate basis upon which to rest professional opinion. In this connection, I suggest that, except where otherwise noted, there should be no omission of any procedure which petroleum geologists would ordinarily employ for the purpose of making dependable statements. Finally the geologist should express his professional opinion as clearly and fairly as he can in language intelligible to the layman.

At the SEC, we have an Oil and Gas Unit, composed of experts who specialize in oil and gas problems. Our geologists and engineers go over the geological statements filed with us to find out whether the full truth is being told to the investor. Opinion plays so large a part in making geological estimates that absolute mathematical accuracy is impossible. Still, within limits, considerable accuracy can be attained. There are areas, as I have already indicated, wherein the reports of geologists should be subjected to scrutiny from the point of view of the

interest of the public investor. That is the job of the SEC. Of course the great majority of the statements filed with us are the products of respectable, honest, capable geological experts. Many of these experts are members of the American Association of Petroleum Geologists.

The virtue of simple honesty would seem easy to maintain. Unfortunately, not all of these geological statements tell the full truth. Some are plain frauds. Others are unintentional but careless misrepresentations. Above all, there are instances of inadequate disclosure. There are few geologists whose reports fall into these categories. Yet there are enough of them to create a problem. Some of them are members of this Association.

The SEC therefore has a keen interest in the professional standards of geologists. There always have been and always will be subtle influences at work to corrupt the high functions which professional geologists perform. When I speak of corruption I don't necessarily mean larceny. I include the application of pressure from employers so that these high functions be exercised solely for the employers' profits. A personal financial interest may influence the geologist to prepare statements which do not fully disclose material facts. I refer to geologizing solely by cash-register standards. I also include the corroding influence of unscrupulous promoters. You and I have known geologists who were but "yes-men" to over-reaching promoters. In short, I mean that the idea of geological service has sometimes been forsaken for geological salesmanship. For these reasons one of the chief problems of geologists is an ethical one. In these regards, petroleum geologists are no different from other professional groups. The lawyers have their shysters, the doctors their quacks, and the geologists their "geo-quacks."

The American Association of Petroleum Geologists is vitally concerned about these "geo-quacks." The Association's Code of Ethics, quoting Article II of the Constitution, provides that,—"The object of this Association is . . . to maintain a high standard of professional conduct on the part of its members; and to protect the public from the work of inadequately trained and unscrupulous persons posing as petroleum geologists."

There is good reason for this Association to be concerned about the professional standards of its members. We all know that a few rotten apples can spoil a whole barrel. The "geo-quacks" create ill-will for the geologists' profession.

Article II of the Association's Code of Ethics deals with the relation of the geologist to the public and his profession. I don't want to

sound as if I were delivering a sermon but I do want to emphasize a few of the principles set forth in the code. A geologist, the code says, in part:

1. should avoid unwarranted statements that might induce participation in unsound enterprises.
2. should not knowingly permit the publication of his report for the purpose of raising funds without legitimate and sound development in view.
3. may accept for his services an interest in the property reported on, but it is desirable that the report state the fact of the existence of the interest.
4. should not give an opinion or make a report without being as fully informed as might reasonably be expected, considering the purpose for which the information is desired. The opinion or report should make clear the conditions under which it is made.

Such principles are, after all, the living difference between professional conduct and non-professional conduct. They introduce the element of public service which distinguishes the profession. True, it is most difficult for the professional to think in terms of the cumulative effect of his daily activities in terms of the ultimate public welfare. While this is not peculiar to the geologist, it is an acute problem in his case because in the final analysis his is a profession affected with a public interest.

Unfortunately, codes of ethics too often remain just codes of ethics. Enforcement of the code by this Association depends largely upon one member reporting violation of the code principles by another member to the executive committee of the Association. Being human, you and I don't like the brand of "tattle-tale" so we pass the buck and fail to report our unethical fellow members. Other professional groups have the same problem.

I want to suggest one way in which the SEC and the Association can work together to put into effective practice the geologists' code of ethics. Part of our job at the SEC, as I have previously said, is to protect the public investor from the "geo-quacks." The Association has the same objective from the point of view of the good of the geologists' profession. We at the SEC have a few ways of dealing with untruthful geological statements. We can refuse to permit the registration statement to become effective, thereby preventing the securities from being sold lawfully. We may induce the oil company to withdraw the untruthful geological material or substitute accurate statements. On the other hand, the SEC may recommend to the Department of Justice that it institute criminal proceedings against the deceitful geologist. The SEC's Rules of Practice also provide that any person who has engaged in unethical or improper professional conduct may be disqualified from preparing any statement filed with the SEC. These methods may be either too mild or too drastic in many cases. The

middle ground would seem to lie in disciplinary action by the Association itself. Judgment by one's fellow members who are expert and aware of changing and current conditions should prove very effective in deterring unwarranted geological statements.

Our mutual aims can be accomplished through some working arrangements between us whereby we coöperate to stamp out "geoquackery" and foster high standards of professional conduct. Therefore, I respectfully suggest that the Association set up a committee to maintain liaison with the SEC. If the SEC uncovers unethical or improper professional conduct by some Association member, it will relay the information to the Association for appropriate action by the Association. The Association can discipline its own members if it deems it appropriate and thereby maintain its high professional standards. The SEC, in performing its duty of protecting investors, may thus provide its administrative machinery to inform the Association of possible infractions of its code of ethics. Not only can we work together in this regard, but there are surely other common problems in connection with petroleum geology which can be talked over to our mutual benefit. If there is real coöperation, the Association's liaison committee can function as an advisory body with which the SEC can consult on mutual problems. Out of this working arrangement can come understanding and coöperation which will be beneficial to both the Association and the SEC.

A similar coöperative arrangement has proved successful in the accounting field. For several years, the SEC has had a working arrangement with the American Institute of Accountants, the Controllers' Institute of America, and the American Accounting Association. The disciplinary committee of the American Institute of Accountants keeps in close touch with the SEC. The American Institute of Accountants has also designated a "Special Committee on Coöperation with the Securities and Exchange Commission" to work with us. The accountants' Special Committee on Coöperation with the SEC had the following to say in its report in 1940.

> The S.E.C. and the accountancy profession have common objectives. Differences of opinion are bound to arise as to ways and means for accomplishing the objectives, but our experience has shown that representatives of the S.E.C. and committees of the American Institute of Accountants can discuss opposing views frankly to their mutual advantage.

I believe that it can be made to work successfully in the petroleum geology field too. The SEC can help you. And you can help the SEC. I sincerely hope that the Association will give serious consideration to this proposal.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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ESTIMATION BY VOLUMETRIC METHODS OF RECOVERABLE OIL AND GAS FROM SANDS[1]

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ABSTRACT

The classical formula for volumetric estimates involving factors for area, sand thickness, porosity, saturation, and recovery is reviewed and the need for modification and amplification of the factors demonstrated. Individual factors are redefined in their new content and methods for their evaluation outlined. Necessity for consideration of both physical and economic effects in the choice of a recovery factor is emphasized. Recovery factors for oils are distinguished from those for gases for co-occurring and produced oil and gas mixtures. Applicability of volumetric reserve estimates to engineering appraisal is discussed and inherent limitations of the procedure set forth.

In conclusion the writers point out that practical accuracy in volumetric estimates of oil and gas reserves is dependent both on the accuracy and completeness of the data available and on the skill and resourcefulness of the engineer or geologist in analyzing and visualizing reservoir conditions and fitting together the fragmentary data into a compatible whole. Similarities with and differences from other fields within his experience should be recognized as well as the practical limitations of the factors involved, their relative importance and relative weight.

INTRODUCTION

In venturing to contribute one more paper to the literature on volumetric methods of estimating recoverable oil and gas from sand fields, it is not the purpose of the writers to offer any new or different methods from those that have been used in the past. It is intended instead to present a critical examination of the factors involved in such a method and to suggest relationships which exist between such factors and other physical phenomena related to the reservoir. By such a procedure it is hoped that when the geologist or engineer is confronted with the practical necessity of preparing an estimate from the data at hand, proper inferences can be drawn and reasonably dependable figures obtained even in the absence of certain data necessary for a complete straightforward solution of the problem.

Throughout the discussion it should be borne in mind that the conditions discussed and inferences suggested must be restricted to cases of relatively undisturbed reservoir conditions and their use can be extended to cases where considerable production has been taken from a part or all of the reservoir only with the full realization of the inaccuracies or inaptness which may result from such extension or application.

[1] Manuscript received, December 10, 1940.

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CLASSICAL FORMULA

The classical formula for calculating the oil recoverable from a given reservoir assumed the following general form and in such form has been used for many years.

$$R = FAtpsr \tag{1}$$

where R = recoverable oil in U. S. barrels
F = factor, 7758 when
A = area in acres of productive sands
t = thickness of sands (average over A)
p = porosity factor
s = saturation factor
r = recovery factor

REVISION OF FACTORS

It is now recognized that many of the factors require extension or revision as to their original content.

Two factors, area and thickness, A and t, respectively, are used in determining the total volume of the reservoir framework and to insure even reasonable accuracy these factors must be carefully evaluated. In a single sand zone or pool the thickness of the oil- or gas-filled portion of the sand may vary greatly, requiring detailed consideration to secure the total volume required. For multiple-sand zones it is commonly necessary to follow lateral trends in sand thickness and, in some cases, such marked lithologic changes as the gradation of a sand into an impermeable siltstone or shale.

Edge waters of the various members of a multiple-sand zone are seldom coincident vertically. Outpost wells drilled several well locations beyond commercially productive limits of a field not uncommonly encounter stringers of oil sand and these sands when their presence is known should be included in the oil-sand volume total since they form a portion of the sand volume drained by the wells upstructure. The same consideration also applies to gas-filled sands, requiring identification and inclusion in the gas-cap volume of many small gas caps of varying areal extent.

The porosity factor, p, as originally conceived, was the percentage of the total volume occupied by interstices. As the interest in reservoir mechanics and recovery methods increased, other concepts of porosity were developed and various methods devised for determining the particular values desired. To-day, when porosity data are to be employed, it is essential that the method by which they were determined be known and the use of the data be in accordance with their nature.

The saturation factor, *s*, requires the greatest modification. In the earliest work the total formation, sand, sandy shale, and shales, was considered wholly saturated; subsequently, only the sand was evaluated. However, the then prevailing assumption was that of 100 per cent oil saturation. Reference to the literature indicates that this very general view was but gradually revised. In 1934, O. L. Brace (1)[4] pointed out the fact that some correction of the saturation factor must be made to allow for oil volume changes "due to reduction in temperature and escape of dissolved gases" and that "An additional factor having a bearing of probable importance on the estimation of reserves is that of contained moisture."

He concluded that

> The influence of dissolved gas and temperature upon expansion of oil bulk is of positive character and readily measurable and allowance may be made for it with reasonable accuracy. Present experimental data suggest that nowhere may this factor be disregarded if results are to approximate actual conditions. Included moisture constitutes an important but little understood factor bearing on the exact solution of these problems. Before a correction for its use may be generally applied, more experimentation must be carried out.

Recently quantitative data on the amount of residual connate or interstitial water present in oil sands have become more abundant, and, more important still, relationships have been suggested which promise to give good approximations of this water content even when no direct determinations are available.

Field and laboratory equipment and methods for determining the volumes occupied in the reservoir under prevailing temperature and pressure of a unit volume of oil and its accompanying gas have been devised by Lindsly (2), Lacey and Sage and co-workers (3), Katz (4), and others. Lacey and Sage in American Petroleum Institute Fundamental Research Project No. 37 are laying the foundation for the calculation of these reservoir gas-oil relations and volumes as functions of reservoir hydrocarbon composition (gas-oil ratio), temperature and pressure. These values are readily determinable by proper surface and subsurface measurements except in the case of the formation gas-oil ratio which must be calculated from information obtained by coring or inferred from the production gas-oil ratio. A suggested method for such inference will be outlined later in this paper.

Notions of the value for the recovery factor to be used in volumetric estimates had their origin principally in examination of depleted sands obtained from oil mines in Pechelbronn and elsewhere, by

[4] Figures in parentheses refer to bibliography.

coring depleted sands as an incident to the development of deeper zones, and from comparisons of actual recovery from fully depleted fields with the total pore space in the sands, assuming complete saturation for the oil sands of these fields. The values for the recovery factor obtained from such calculations were generally low since the comparisons were made in ignorance or disregard of the presence of substantial

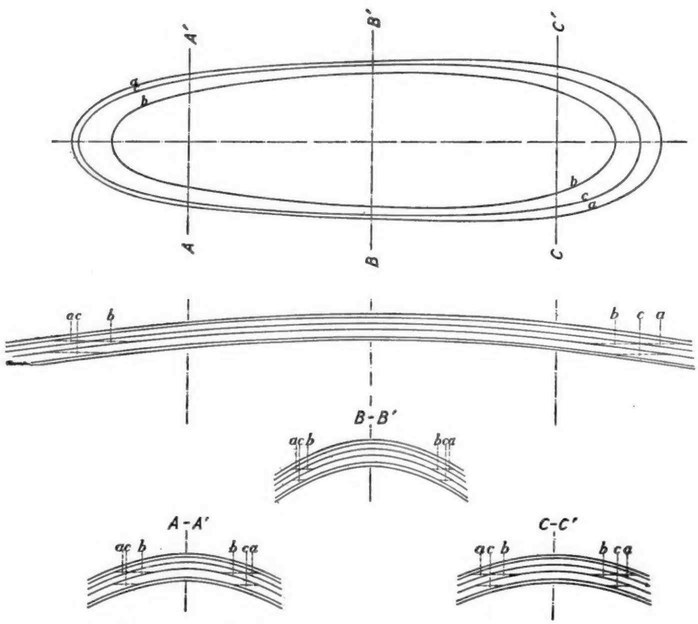


FIG. 1.—Type A is large, multiple sand, varying sand-texture reservoir containing both gas-saturated oil and free gas.

amounts of interstitial water. However, a compensating error existed in the disregard of a change in oil volume resulting from temperature and pressure changes when the unit of production was withdrawn from the reservoir. Whether a single overall recovery factor is used or two separate factors are employed, one to cover oil physically retained by the sand and one to allow for oil made mechanically or economically non-recoverable by varying location of wells, lateral change of facies in the sands, ineffectiveness of completion and well condition, the choice of a proper value for the recovery factor remains the greatest single difficulty in the volumetric estimation of reserves.

TYPE ILLUSTRATIONS

Several hypothetical illustrations have been prepared to aid in discussing methods of selecting and averaging factors to be used in calculating recoverable oil and gas reserves.

Type A (Fig. 1) is a large, multiple-sand, varying-sand-texture reservoir containing both gas-saturated oil and free gas. The several

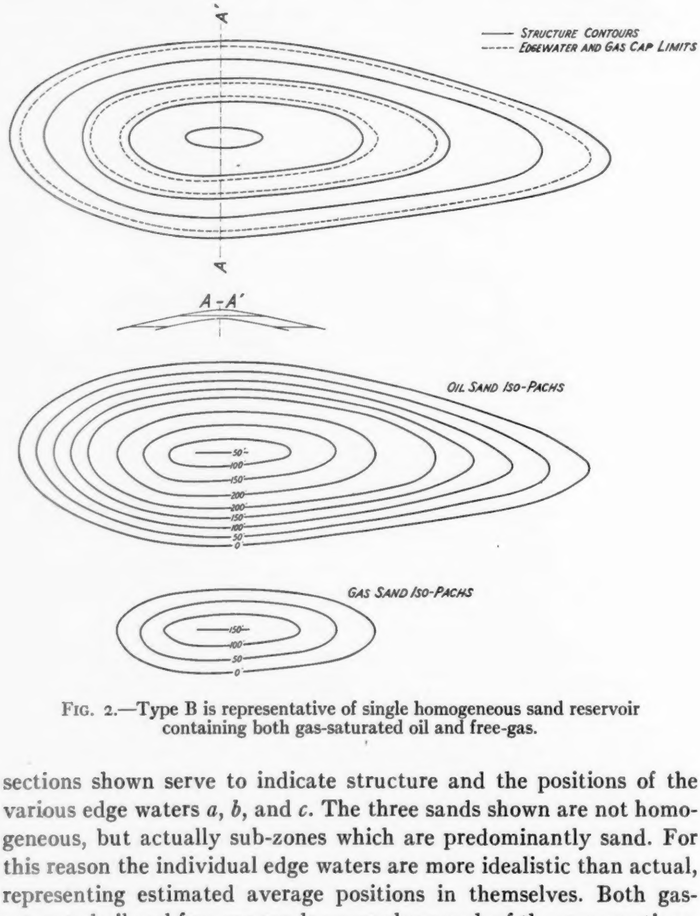


FIG. 2.—Type B is representative of single homogeneous sand reservoir containing both gas-saturated oil and free-gas.

sections shown serve to indicate structure and the positions of the various edge waters *a*, *b*, and *c*. The three sands shown are not homogeneous, but actually sub-zones which are predominantly sand. For this reason the individual edge waters are more idealistic than actual, representing estimated average positions in themselves. Both gas-saturated oil and free-gas sands occur along each of the cross sections.

Type B (Fig. 2) is representative of a single homogeneous sand reservoir. The sand is of regular texture and contains both gas-

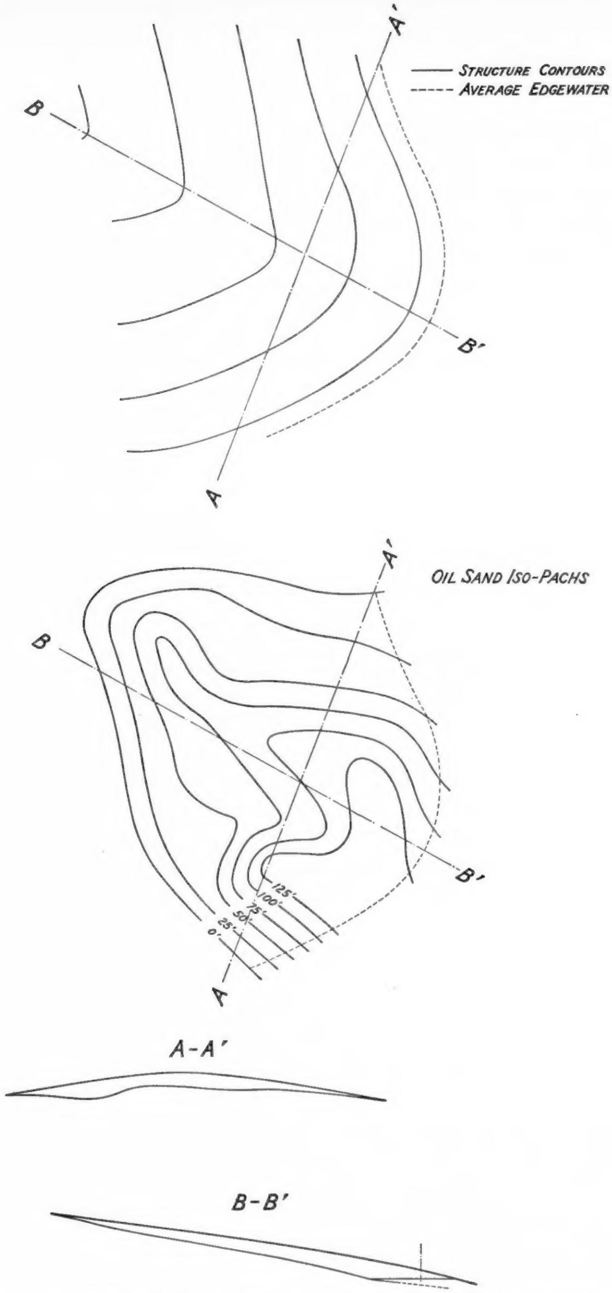


FIG. 3.—Type C is illustrative of irregular sand reservoir. Sand is homogeneous and contains oil which is only partially saturated with gas.

saturated oil and free gas. Sand characteristics are assumed to be sufficiently constant as to allow the use of single average values of total porosity and permeability (and therefore of interstitial water) for the whole reservoir. Edge-water and free-gas limits are indicated in plan along with structural contours and in section. Oil sand and free-gas sand isopachs are shown.

Type C (Fig. 3) is illustrative of an irregular sand reservoir. The sand is homogeneous and contains oil which is only partially saturated with gas. Structural contours of the top of the oil sand are shown as well as cross and longitudinal sections. The use of an average edge-water position is illustrated on the longitudinal section and the contour plan. Oil-sand isopachs are also set forth. In this case, as in that of type B, the sand is assumed to be such as to allow the use of single average values of sand characteristics.

CHOICE OF AREA TO BE CONSIDERED

Two optional bases of procedure are available in solving volumetric estimates; namely, the total reservoir and the unit volume. In the former the reservoir is treated as a single entity (illustration, type C) and the total void volume determined, while in the latter a typical unit such as an acre-foot is considered and then extended to the reservoir by multiplying by the number of acre-feet of sand to be drained or by the volume to which the unit acre-foot values are applicable (types A and B). Gas caps can be treated either separately (type B) or as a percentage of the total reservoir or unit volume (type A). In all cases care must be exercised that the parameters employed be assigned average values representative of that part of the reservoir to which the calculation is to be extended.

Choice of the basis to use or the area and sand thickness to be considered depends largely on the completeness of the pertinent data available, the size of the total reservoir, the degree of variation of the factors, and the fluid-content composition. In fields where the well-spacing unit is considered to be greater in area than that which can be drained by a well the unit-volume basis must be used and expanded to the estimated drainage area only. Unit volumes representative of restricted areas should be used for large fields or ones in which the factors and fluid-content composition vary greatly (type A), as well as when an individual property or subdivision of the field only is considered.

CHOICE OF AVERAGE VALUES FOR FACTORS

Before the method of averaging factors to be used is determined the completeness of data available and the magnitude of value variation

should be considered: first, those from an individual well section and secondly, those from groups of wells. Where sand characteristics of a complete section are available and the magnitude of the individual values does not vary greatly, a simple arithmetic average may suffice. However, if the sand characteristics do vary materially, values weighted for sand thickness should be used.[5]

Average values as determined for individual well sections may be plotted in plan and weighted by area where it is indicated desirable (type A). This method may also be used as an aid in determining whether the reserve calculation should proceed with total or unit volumes, and if unit volumes are used the extent to which the units are to be extended.

Where the wells from which data are available are distributed erratically over a large area, porosity and sand-thickness maps may be prepared and values assigned to predetermined unit areas by interpolation, taking into consideration all subsurface geological data available as to structure, depositional changes and position of edge waters (type A). Similarly the variation in penetration of the wells into the productive section and the nature of the hydrocarbons produced must be considered. Average values of sand characteristics may be more inclusive than average fluid-content composition (type B), or the reverse may be the case and these conditions must be considered.

FACTORS

SAND EXTENT

Determination of the sand extent or area factor A must in most cases be based on a combination of well data and geologic structure interpretations since even the *commercially productive* area will seldom be completely delineated by drilling in any but completely developed fields. Again the area subject to drainage will seldom, even in single-sand fields, be sharply outlined as a result of drilling, for the oil-edge water interface if represented in plan appears as a band of some width rather than as a single line. Where multiple-sand zones of some thickness occur each with a separate edge water, this band may be of even greater width and while no well locations can be justified in this fringe area a very considerable amount of sand may exist there which will contribute oil and gas to the wells situated up structure. The area drained therefore nearly always exceeds by a substantial amount the so-called "proved area," which by definition is the area in which commercially productive wells can be obtained. Outpost wells which fail of

[5] To avoid the need of determining average sand characteristics by weighting, sand samples of a cored section are commonly taken at regular intervals.

commercial production are commonly of as much value in determining the area drained as are the edge wells in the proved area.

Where reasonably satisfactory structure-contour maps are available for the productive interval and the general plane of the oil-edge water interface can be determined from well data, whether it be horizontal or tilted, a fairly dependable delineation of the area drained can be inferred by tracing the intersection of the interface plane with the structure as represented by the contoured surface (types B and C).

If estimates are to be made for specific tracts or for areas less than the total reservoir, attention must be given to the conditions imposed by the necessary assumption that no movement of oil and gas takes place in either direction across the boundaries of the area in question. The position of the tract or area on structure and its proximity to edge water and the rate of encroachment of the edge water or the presence of a large primary gas cap adjacent to but not currently extending onto the tract may require special treatment either in the sand volumes chosen or the oil-recovery factor to be used.

SAND THICKNESS

The actual thickness of the reservoir sand can usually be determined without great difficulty from the core record or, in the absence of mechanical coring, inferred from the electric log. Where cores are taken and analyzed for fluid content, porosity, and permeability, direct determination can be made of the thickness of productive sand penetrated, as well as a division of this sand into gas-filled and liquid-filled portions (type B). Where core recovery is poor, question frequently arises as to what characteristics should be assigned to the missing footage, but where mechanical coring has been supplemented by electric logs the nature of the formation not recovered can usually be readily deduced by correlation of the recovered footage with these electric logs.

Greater difficulty is experienced where no mechanical cores are taken and where the determination must be made entirely from the electric log. Although much work has been done on the quantitative interpretation of these logs, the multiplicity of factors which affect them have to date, to the knowledge of the writers, left the problem only partially solved. It is recorded, where correlation has been attempted between completely cored sections and the corresponding electric log, that when the zone contains repeated intercalations or thin beds of shale, these beds have not been detected by the electric-logging device. Under such conditions sand thickness estimated from the electric log would be in error.

Recourse is frequently had to calibration of the electric log by means of formation tests. Where doubt may exist as to the presence of permeable sands formation tests of short intervals are helpful. In addition the nature of the fluids contained in the formation tested is determined. Such tests may only serve, however, to calibrate the electric log so long as the known factors or conditions affecting the recorded values are not varied too widely.

POROSITY

Porosity, that property of a reservoir rock that permits the reception and storage within it of fluids, is the next factor to be examined.

Tolman (5) has defined porosity as "the property possessed by a rock of containing interstices without regard to size, shape, interconnection or arrangement of opening. It is expressed as a percentage of total volume occupied by interstices."

Coberly and Stevens (6) distinguish between absolute and effective porosity as follows.

> The absolute porosity of a rock or sand may be defined as the volume of the interparticle space expressed as a percentage of the total rock volume. The effective porosity as contrasted with the absolute porosity is the volume of the interparticle spaces which communicate with passages of sufficient size to permit the entrance or recovery of oil or gas, also expressed as percentage of the total rock volume.

It should be noted that from an economic standpoint, where time is an all-important factor, "passages of sufficient size to permit the entrance of oil or gas," that is to say to permit the rock to become an oil or gas reservoir, may not be "passages of sufficient size to permit the . . . recovery of oil or gas." This limiting condition alone obviously makes the measurement of effective porosity difficult. It is perhaps mainly for this reason that current practice tends toward disregard of effective porosity and the use of total porosity as determined by some rapid method such as that outlined by Pyle and Sherborne (7).

Where porosity data are not available, recourse must be had to inference from accumulated data on other oil fields where there are similar producing sands at like depths. It has been established in many California fields that while some variation may be expected with position on structure, degree of folding and subsequent geologic history, reasonably close correlations can be made based on age and depth to allow choice of approximate porosity values.

SATURATION

It would seem unnecessary to more than mention the fact that the pore spaces of the reservoir rock will at all times have a total fluid

saturation of 100 per cent. However, since estimates of space available for hydrocarbon saturation are obtained by difference, that is to say, by subtracting from the total pore space that space occupied by water, such a statement may not be wholly without point.

As outlined in the introduction, the notion of residual connate or interstitial water in a sand reservoir producing clean (water-free) oil is a relatively recent one. Connate water has been defined by Tolman (8) as "water entrapped in the interstices of a rock at the time it was deposited." However, it is only with a portion of such water that we are concerned and it is therefore suggested that the term "residual connate water" or "interstitial water" having the following definition should be emphasized: the amount of water remaining in the sand after the accumulation of oil and gas in the pore spaces of the reservoir.

Objection might be raised to the term "residual connate water" in that the water actually existing currently in the pore spaces may not be wholly composed of the original connate water but may be water that has migrated into the sands subsequent to deposition. The use of the suggested term "interstitial water" would appear to fully meet such objections.

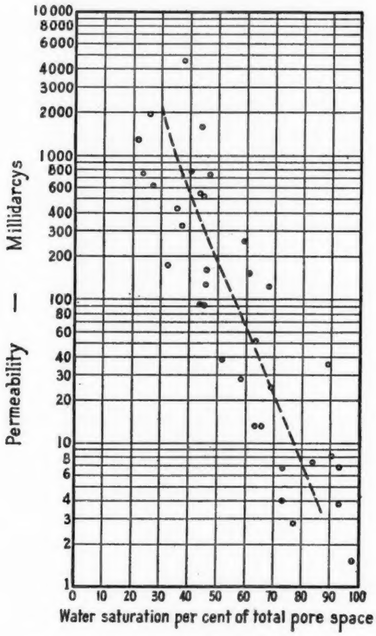
Methods for the determination of the interstitial water content of oil sands have been discussed by Horner (9), Pyle and Jones (10), and Schilthuis (11).

Due to the inherent difficulties in their determination actual data on the amount of interstitial water in oil sands are commonly meager and the engineer may have to obtain a value for this factor from other data available. The extent to which the hydrocarbons, oil and gas, are able to displace the original connate water during the accumulation period is a function of many factors, such as viscosity of the oil, differential pressures affecting the accumulation, grain-size distribution, and composition of the sands; but the final result of the combination of these factors may be conveniently and satisfactorily expressed as a relation between permeability and interstitial water, as illustrated by Figure 4.

Since the permeability of the sands is a factor entering into the estimate at several points a brief consideration of this reservoir characteristic is necessary. Permeability has been defined as the ability of the formation to transmit fluids. More specifically it is defined as "the rate of flow of a specified fluid through a unit cross-section of the porous medium under a unit pressure gradient and conditions of viscous flow" (12).

Where core material is available, permeability may be measured directly by any one of several described methods (13, 14, 7).

In the absence of permeability data, recourse must be had to a somewhat roundabout procedure by which average permeability can be determined from a well's production characteristics (15, 7). Kemler and Poole (16) point out the relationship between permeability and production rate and offer a formula for the calculation of permea-



RELATION BETWEEN PERMEABILITY OF CORES AND CONNATE-WATER SATURATION

After Schilthuis for Anahuac Field

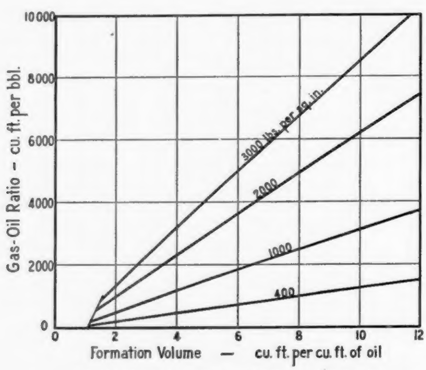
A.I.M.E. Petroleum Development and Technology 1938

FIG. 4

bility when certain other data commonly at hand are available. W. S. Walls (17) offers a somewhat similar solution of the same problem with substantially the same data required. By application of one of these suggested formulas or by a similar solution, average permeability values can be determined for the reservoir in question and the value so obtained used to deduce the amount of interstitial water and hence by difference the net effective pore space available for hydrocarbons.

Because of the solubility of gas in oil and the compressibility of

gas, the volumes of oil and gas at the surface are vastly different from their subsurface or reservoir volumes. In the process of production temperature and pressure decrease, gas expands and oil volumes shrink. To fix these volume changes standard atmospheric conditions of 60°F. and 14.73 pounds per square inch absolute have been established (Amer. Petrol. Inst.) and the term "formation volume factor" (3) generally accepted. This term refers to the subsurface volume occupied by a unit volume of oil and its associated gas, both measured at the standard conditions of temperature and pressure (Fig. 5). Where the formation-volume factor applies solely to oil and dissolved gas its reciprocal is called "shrinkage factor" and refers to the fractional re-



FORMATION VOLUMES AT 190 DEG. F.

After Sage and Lacey for Dominguez Field
A.P.I. Drilling and Production Practice 1935

FIG. 5

duction in volume of the oil accompanying a reduction of temperature and pressure from reservoir to standard surface conditions.

Formation-volume or shrinkage factors may be obtained by laboratory measurement using representative samples of the hydrocarbons involved (3). In the absence of specific measurements formation-volume and shrinkage factors may be calculated by the use of equilibrium constants of Sage and Lacey (18) or Katz (19) in which cases hydrocarbon compositions must be known or by the use of the more generalized correlations of Gosline and Dodson (20) in which case the types of oil and gas involved and their specific gravities are used.

The accurate use of formation volumes is closely allied to that of securing representative samples of the hydrocarbons in place within the reservoir. Where oil occurs undersaturated with gas so that pro-

ducing subsurface pressures are in excess of bubble-point pressures either bottom-hole (21–24) or surface samples will be representative. This is definitely not the case where oil occurs gas saturated or with excess gas. In these cases disproportionately large quantities of gas will be produced with the oil and this condition must be recognized (20, 25). In gas wells, where producing subsurface pressures are not greatly lower than static pressures, it is probable that the hydrocarbon composition of the produced fluids closely approximates that of the gas reservoir.

As before mentioned, dissimilarity of reservoir-fluid content may determine the choice of reservoir subdivisions so as to make the hydrocarbon composition of each division uniformly representative (type A). Large errors in reserve calculations can result from a too inclusive choice of a formation volume or shrinkage factor. The relative proportion of gas-cap material must therefore be known. Direct measurement of the gas-containing sands where continuous cores are available is, of course, the most accurate method for this determination. Unfortunately, continuous cores are not ordinarily available. Partially cored sections accompanied by areal and sectional structural correlations may be sufficient to delineate gas-filled sands, particularly where the occurrence is in regular single-sand reservoirs (type B).

In the more complicated or multiple-sand reservoirs the proportion of gas-filled sands can be calculated from initial production volumes if certain general and simplified assumptions are made, as follow.

1. Sand is sufficiently uniform so that dependable average characteristics can be determined
2. Permeabilities of oil and gas sands are equal or permit relative evaluation
3. Homogeneous radial flow of both oil and gas is attained
4. Drainage radii of oil and gas production are equal

Integration of Darcy's law of fluid flow through sands results in the well known radial-flow equation (26):

$$Q = \frac{2\pi kh(P_e - P_w)}{\mu \log_e \dfrac{(r_e)}{(r_w)}} \cdot \tag{2}$$

This equation holds for either gas or oil provided the fluid volume is measured under average producing conditions. Dividing the gas rate by the oil rate gives the free gas-oil ratio of production:

$$\frac{Q_g}{Q_o} = \frac{\mu_o}{\mu_g} \cdot \frac{k_g}{k_o} \cdot \frac{h_g}{h_o} \cdot \tag{3}$$

Reducing this equation to practical units, gives

$$G_f = 5.61 \cdot \frac{x}{1-x} \cdot \frac{\mu_o}{\mu_g} \cdot \frac{k_g}{k_o} \cdot \bar{p} \cdot L \cdot \frac{D_{\bar{p}} T_a}{P_a T_f} \cdot \tag{4}$$

The total production gas-oil ratio is

$$G_t = G_s + G_f. \tag{5}$$

Where Q = rate of flow in cm.³/sec.
k = permeability in millidarcys
h = sand thickness in centimeters
P_e = reservoir pressure in atmospheres
P_w = subsurface well pressure at sand face in atmospheres
μ = viscosity in centipoises
r_e = drainage radius of well, in same units as
r_w = well radius
x = fraction gas sand of total sand
$\bar{p}$ = algebraic mean pressure under producing conditions = $\frac{P_w + P_e}{2}$, in pounds per square inch absolute
P_a = atmospheric pressure in pounds per square inch absolute
L = formation volume factor for average producing conditions
$D_{\bar{p}}$ = Boyle's law deviation factor for average producing conditions
T_a = atmospheric temperature in degrees Fahrenheit absolute
T_f = formation temperature in degrees Fahrenheit absolute
G_f = free gas-oil ratio in cubic feet per barrel
G_s = saturation or bubble-point gas-oil ratio in cubic feet per barrel, and
G_t = total produced gas-oil ratio in cubic feet per barrel.

Subscripts "o" and "g" stand for oil and gas, respectively.

Evaluation of the physical constants in equations 4 and 5 permits the determination of the relationship between produced gas-oil ratio and fraction of gas sand in the reservoir. An example has been worked out to illustrate the procedure.

Given: Reservoir pressure = 2,385 lbs. per sq. in. abs.,
Reservoir temperature = 173°F.,
Formation volume factor = 1.31,
Saturation gas-oil ratio = 490 cu. ft. per bbl., and
Average oil sand permeability = average gas sand permeability.

For a producing status of 500 lbs. per sq. in. differential "bottom-hole" pressure, the following physical factors may be obtained from various published sources:

With the average producing pressure of 2,135 lbs. per sq. in. (i.e., $\left(\frac{2,385+1,885}{2}\right)$,

Saturated oil viscosity = 0.745 centipoises
Gas viscosity = 0.01905 centipoises, and
Deviation factor = 1.188.

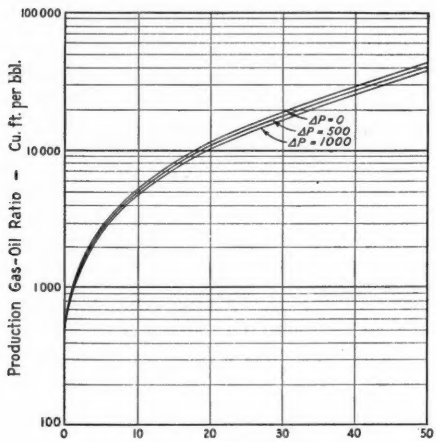


FIG. 6.—Relation between per cent gas sand and production gas-oil ratio for particular case.

Taking the condition of 10 per cent gas sand, equation 4 may be solved as:

$$G_f = 5.61 \frac{(0.10)}{(1 - 0.10)} \frac{(0.745)}{(.01905)} (1)(2,135)(2,135)(1.31) \frac{(1.188)}{(14.73)} \frac{(520)}{(633)}$$

$$= 2,635.$$

Then from equation 5,

$$G_t = 4,520 + 490 = 5,010.$$

By assuming varied values for the fraction of gas sand, and allowing the differential pressure to be consecutively 0, 500, and 1,000 lbs. per sq. in., a series of calculations similar to the foregoing may be made and

the results plotted as shown in Figure 6. By applying such a chart to individual well production data, a gas-oil contact for each well can be determined. When plotted in section these contacts permit the establishment of an average gas-oil interface plane for the pool (type A). An alternate procedure would be to determine the in-place gas-oil ratio, plot these in plan and weight them for area.

NON-RECOVERABLE OIL

In the consideration of the quantity relationships which will exist between hydrocarbons in place and those produced, commonly expressed as recovery factors, it should be noted that no single factor can be applied to both the liquid and gaseous hydrocarbons. In other words, one must expect a different percentage of recovery to obtain for the liquid or oil phase than for the gas phase. Disregarding for the moment the fact that phase changes take place during hydrocarbon movement from the reservoir to the separator at the surface and that oil in the tank may have been vapor-phase material in the formation and *vice versa*, attention may first be given to the factors affecting hydrocarbon recovery.

Two classes of effects or factors account for the failure to recover all of the oil and gas from the underground reservoir and the determination of reasonable recovery factors to be used in the estimate depends on a proper understanding and weighting of these effects. The first class might be termed sand retentivity or physical effects to distinguish them from the mechanical and economic factors which are included in the second class.

When a core taken from an oil sand is removed from the core barrel there remains in the pore spaces only a fraction of its original hydrocarbon content since the core during its removal from the bottom of the hole has been subjected to a pressure drop from reservoir to atmospheric pressure in addition to a certain amount of flushing by water from the drilling fluid. The core in effect corresponds with a portion of the producing formation which has been depleted by ordinary gas-expansion production procedure plus a possible further depletion due to water flushing (27). It is recognized that the time factors are not consistent in this analogy; however, this is not considered of serious import. The amount of oil retained in the core as related to the pore space available for hydrocarbons corresponds then with the percentage of the oil in the reservoir which will be retained in the sands unrecoverable by corresponding production methods.

In a reservoir with a stationary edge water, only that part of the oil will be recovered which will be driven into the hole by the expand-

ing gas unless secondary methods of recovery are employed. Where edge water encroaches an additional amount of the oil will be recovered from the water-flushed sands. Fortunately considerable numbers of data are available from core examination and experimental work on water-flooding and other secondary-recovery methods which make possible reasonable correlations between pertinent factors such as viscosity of oil, temperature, gas-oil ratio, and permeability of sand and the percentage of oil to be retained or recovered in accordance with a projected production procedure.

It is more difficult to evaluate the proportion of the oil which will be non-recoverable through a combination of mechanical and economic factors. In the comparison afore noted the core was reduced to atmospheric pressure when brought to the surface and every part of it given equal opportunity to deplete itself. Such a condition can never be even approximated for the reservoir as a whole. The well itself is a mechanical entity and never 100 per cent perfect even when first completed. Seldom is complete penetration of the sand effected and such initial penetration as is had is gradually lost actually or effectively through plug backs to exclude water, ineffective clean-out jobs or plugged pores and liner perforations. Again, due to lithologic changes and variations in permeability, both horizontal and vertical, some oil is trapped in place by encroaching edge water and left unrecoverable. Faulting in the producing beds, commonly unsuspected in early stages of development, ordinarily greatly affects recovery when well spacing is planned without knowledge of the fault pattern. Perhaps of somewhat less importance in magnitude but nevertheless of significance is the amount of oil which will be left non-recoverable because of cessation of production operations when wells no longer are considered commercial producers. The economic limit for a well is determined by many independent factors such as price of oil, royalty rate, size of operations, and other variables the control of which is not with the engineer but allowance must be made for them nevertheless.

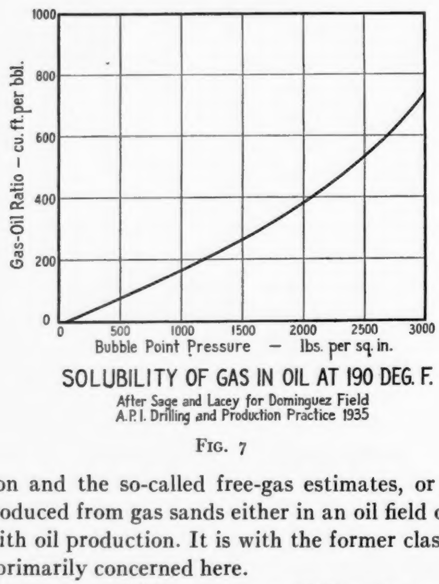
The effect of well density with consequent variation in drainage area must be considered in relation to mechanical non-recovery as well as to non-recovery arising from sand retentivity. With close spacing a lower retention may be expected because of the mechanical factors enumerated and since more complete pressure depletion may be effected.

While sand retentivity can be approximately determined, mechanical recovery can best be obtained by inference. Where a field of known reservoir characteristics is largely depleted and has a type of production history that makes possible an estimate of its ultimate production

by a decline-curve method, the overall recovery factor may be calculated by comparing volumetric reserve estimates with accumulated production plus future production estimated by the decline curve. In this case the mechanical non-recovery factor would be the difference between the overall non-recovery factor and the sand retentivity factor.

NON-RECOVERABLE GAS

Gas-reserve estimates fall naturally into two classes, namely, estimation of the producible amount of gas immediately associated with



SOLUBILITY OF GAS IN OIL AT 190 DEG. F.
After Sage and Lacey for Dominguez Field
A.P.I. Drilling and Production Practice 1935

FIG. 7

oil production and the so-called free-gas estimates, or gas reserves which are produced from gas sands either in an oil field or wholly unassociated with oil production. It is with the former class of estimate that we are primarily concerned here.

Due to its greater mobility and expansibility the quantity of free gas that will be left in the pore spaces of a reservoir is relatively negligible in amount and may be calculated, having made necessary future reservoir-pressure predictions, when oil-recovery calculations have been completed. Of more importance as far as unrecoverable gas is concerned is the amount of gas that will be held in solution in: (a) the sand-retained oil, and (b) the mechanically non-recoverable oil. Calculations may be made based on pressure assumptions and gas-solubility relations, see Figure 7, and the quantity of gas so held in solution related to the original in-place estimates to give a gas non-recovery factor.

In assigning values to the pressure function an estimate must be made of the lowest effective pressure to be attained by the non-recoverable oil. Of influence in this connection would be well density, rate and distribution of oil production, activity of edge water, structural position of the property under consideration, and physical characteristics of the oil sands.

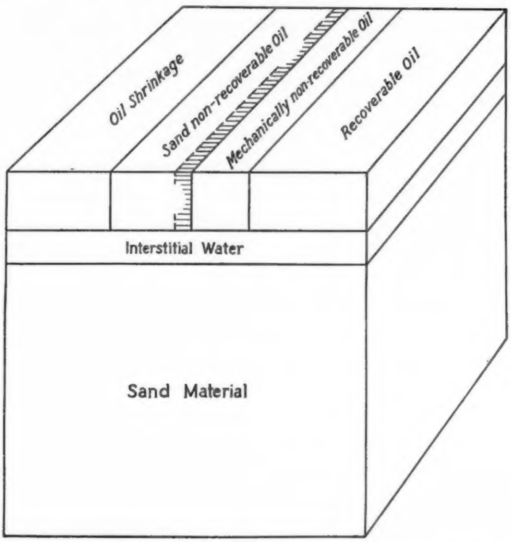


FIG. 8.—Block diagram illustrating unit volume of oil sand.

Methods for calculating reserves of free gas have been described in publications (28). However, in passing, it should be noted that in cases of non-delimitable primary-occurring gas caps associated with oil sands the free-gas volume should be treated with the oil in the calculation of formation volume factors by the method previously outlined for inferring the proportion of the reservoir occupied by gas-cap material.

RECOVERABLE OIL AND GAS

In the preceding discussion of the several factors involved in volumetric estimates, mention has necessarily been made of their place and use in the recovery estimate. It may be well, however, to summarize the technique of making the estimate, apart from the consideration of the factors even at the risk of some repetition.

Figure 8 illustrates the treatment of a unit volume of the reservoir framework step by step to obtain the final desideratum, the volume of the oil to be recovered. This unit is made up of sand grains plus pore spaces available for fluid storage. Of this total pore space a portion is occupied, permanently so far as the estimate is concerned, by interstitial water, leaving by difference the space available for hydrocarbons. Since it is desired to express the estimate of recoverable oil in terms of surface oil, this space available for hydrocarbons must be related to surface conditions by the application of the shrinkage factor, the reciprocal of the formation volume factor. The balance of the unit sand volume represents the surface volume occupied by oil, a portion of which will be retained in the sand, an additional portion of which will be mechanically non-recoverable and the remainder, by difference, represents the amount to be recovered. Where estimates are made after oil has been produced, this past production must be deducted from the estimated recoverable oil to obtain the future recovery or oil reserves.

Little remains to be said regarding the mechanics of gas-reserve estimates in addition to the considerations in the preceding paragraphs. The total gas to be recovered comprises a total of (a) all of the gas occurring originally in solution in the oil recovered, (b) a part of the gas occurring originally in solution in the sand retained and mechanically non-recoverable oil, and (c) a part of the originally occurring free gas, if any. As stated, the amount of gas to be recovered, both free and that from the oil which is to be left in the reservoir, will vary with the minimum gas-oil equilibrium formation pressure attained during production. The accuracy of the recoverable gas estimate is therefore largely dependent on the prediction of future formation pressures within the reservoir.

Adsorption gasoline and condensate recovery can be calculated on a basis of experience, recoveries corrected as may be necessary in accordance with projected production procedures or on a basis of occurring oil and gas analyses and assumed trap separation and production procedure.

ASSUMPTIONS AS TO WELL SPACING

Volumetric estimates necessarily assume that the projected well density will be such that all parts of the reservoir will be effectively drained, the degree to which the drainage is effected being reflected in the mechanical recovery factor. If the well density is too sparse for this the unit-volume approach for an estimation must be employed and the recovery per unit extended only to the probable drainage area of each well.

Where the lithologic character of the producing formation varies to the extent that some members will be adequately drained while others will not, special allowances must be made for this condition in the choice of the mechanical non-recovery factor. In multiple-zone fields where wells are completed in single zones the ultimate well density of the upper zones will be increased by "plug-back" operations in the deeper-zone wells. The oil which can thus be economically recovered by repeated "plug-back" and perforating is a part of that which would otherwise be mechanically non-recoverable and the choice of this factor must be made in this light.

RATE OF OIL AVAILABILITY

All volumetric estimates have the inherent disadvantage of not in themselves providing any notion of the time necessary for the indicated total production to be recovered nor of the relative rate of such recovery. Such essential data must be derived from supplementary studies. Cumulative-production curves in which the total production to date is plotted against time can be related asymptotically to the estimated ultimate recovery and a notion of the probable time necessary to recover any given amount of the oil estimated. Many other forms such as rate-time, pressure-time, and pressure-cumulative production curves have been devised, and, depending on the nature of the data available, may lend themselves to workable rate of availability estimates.

Another form of curve, as yet untested, may be useful in this connection. This type of curve could be called a unit-decline curve and would relate many of the variables affecting the decline of production rate to unity or a fixed reference. For example, in connection with well penetration into a sand and shale zone, instead of treating all of the wells in the field similarly, the well's production rates would be reduced to that attributed to a single average foot of permeable sand penetrated by the well.

PROBABLE ERRORS

Consideration of the nature of the data involved and the means by which they are obtained and the probable errors inherent in volumetric estimates may well be visualized by again referring to Figure 8, the unit-volume illustration. For any given unit volume the amount of space occupied by sand grains can be measured in a laboratory with any desired degree of accuracy, the real test so far as the validity of the estimate is concerned being the representative nature of the samples examined. Interstitial water volumes can be obtained by direct measurement only with relatively great difficulty and therefore

must usually be inferred as previously outlined. For this reason a considerable error in the net pore space calculated may be expected.

The formation volume factor or its reciprocal the shrinkage factor may be determined in the laboratory for particular samples of hydrocarbons and at reservoir temperatures and pressures by methods which are well established. Here again the validity of the hydrocarbon samples controls and affects the accuracy of the final estimate.

Sand-retained oil quantities can be determined experimentally in the laboratory with results that are believed to closely approach field conditions. Furthermore, oil saturations determined by core analysis are considered to be similar to those which obtain in the reservoir upon pressure depletion. The mechanical non-recovery factor is the most difficult to evaluate and may be characterized as merely an intelligent guess based on accumulated experience from fields which are already substantially depleted. By the use of many measurable factors in the estimate the magnitude of this purely experience factor has been reduced. As more experience is had, better and more accurate control of the mechanical non-recovery factors will be possible.

Solution gas-recovery estimates are not as frequently made as are recoverable oil estimates. Here again experience must be called upon to evaluate various factors of the estimate.

CONCLUSIONS

With the practical disappearance of unrestricted production in American oil fields the utility of the once universally employed decline-curve method for estimating reserves has in a large measure been destroyed. Many methods have been employed in its place (29); among these the volumetric method has one preëminent advantage. As soon as the sand is cored and the necessary factors determined it is possible to make unit-volumetric estimates. Furthermore, these estimates may be expanded into estimates of field reserves as drilling progresses and the field limits are delineated.

When production has progressed sufficiently for time-rate values to be available, rate of recovery studies may be made and present-worth calculations based thereon for appraisal purposes with a higher presumption of accuracy than possible with decline-curve or other methods at the same period of the life of the field.

Practical accuracy in volumetric estimates of oil and gas reserve is dependent both on the accuracy and completeness of the data available and upon the skill and resourcefulness of the engineer or geologist in analyzing and visualizing the reservoir conditions and fitting together the fragmentary data into a compatible whole, recognizing

similarities with and differences from other fields within his experience as well as the practical limitations of the factors involved, their relative importance and relative weight.

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VOL. 25, NO. 7 (JULY, 1941), PP. 1327-1342, 3 FIGS.

THRUST FAULTING AND COARSE CLASTICS IN TEMBLOR RANGE, CALIFORNIA[1]

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ABSTRACT

In the region of Recruit Pass the Temblor Range consists of Miocene strata overlain by pre-Cretaceous crystalline rocks and Oligocene and upper Miocene sediments of the Recruit Pass thrust sheet. This thrust cover was folded with the underlying strata, though in somewhat lesser degree.

The Recruit Pass fault on the southwest flank of the range dips southwestward toward, and in places is seen to be cut by, a northwest-trending vertical fault. This is believed to be the northeasternmost element of the San Andreas Rift zone, a strip 2 miles wide covered by faulted Pliocene, bounded on the southwest by the line of recent activity that is generally called "the Rift." The crystalline rocks are not native to Temblor Range but were thrust over it from a source either within, or to the southwest of, the Rift zone.

The major movement on Recruit Pass fault was certainly pre-Quaternary and perhaps as early as latest Miocene. It is suggested that movement began during Santa Margarita (upper Miocene) time, and that the materials of the fanglomerate lenses in Santa Margarita shale found on the northeast flank of the range came from the crystalline rocks which were thrust into the area tributary to the basin of shale deposition.

GENERAL STRUCTURE

The Temblor Range, which is the most southeasterly of the individual ranges that make up the Coast Range, extends from Polonio Pass (west of Lost Hills oil field) southeasterly to the vicinity of Maricopa, where it merges with the foothills of the western end of the east-west trending San Emigdio Range. The San Andreas Rift zone may be said to mark the southwestern edge of the Temblor Range, and on its opposite side is the San Joaquin Valley, into which the range sends southeast-trending spurs, such as Elk Hills and Buena Vista Hills.

The range consists of two parts, arranged *en échelon*, the northern one lying northeast of, and extending southeast of, the northerly end of the southern part. An oblique-trending fault which extends along the southwest side of Little Santa Maria Valley (4 miles west of McKittrick) and thence N. 60° W. across the crest of the range appears to mark the natural boundary between the two parts. The northern part is an anticlinal uplift in which Cretaceous strata form the visible core, flanking which are Tertiary rocks. The southern part of the range is that of primary concern in this paper. It is essentially anticlinal and, save for certain pre-Cretaceous crystalline rocks, the oldest rocks exposed in it are Oligocene.

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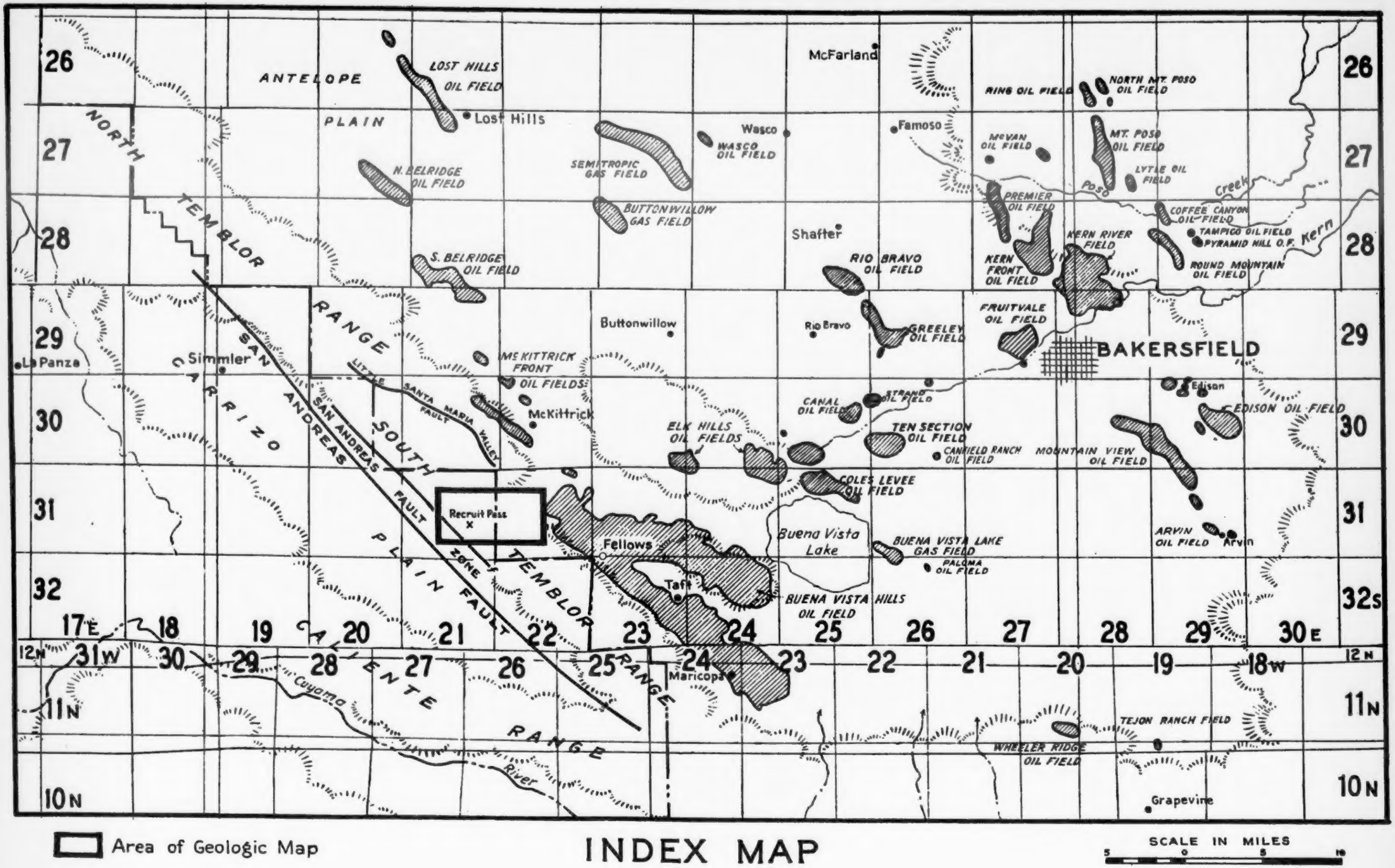

INDEX MAP
Area of Geologic Map
SCALE IN MILES
ANTELOPE
PLAIN
NORTH
TEMBLOR
RANGE
SOUTH
TEMBLOR
RANGE
CARRIZO
PLAIN
CALIENTE
RANGE
SAN ANDREAS
SAN ANDREAS FAULT
FAULT ZONE
LITTLE SANTA MARIA VALLEY FAULT
Cuyama
River
Poso
Creek
Kern
LOST HILLS OIL FIELD
Lost Hills
N. BELRIDGE OIL FIELD
S. BELRIDGE OIL FIELD
SEMITROPIC GAS FIELD
BUTTONWILLOW GAS FIELD
WASCO OIL FIELD
Wasco
McFarland
Famoso
Shafter
Buttonwillow
Rio Bravo
RIO BRAVO OIL FIELD
GREELEY OIL FIELD
RINS OIL FIELD
NORTH MT. POSO OIL FIELD
McVAN OIL FIELD
MT. POSO OIL FIELD
LYTLE OIL FIELD
PREMIER OIL FIELD
KERN FRONT OIL FIELD
KERN RIVER FIELD
COFFEE CANYON OIL FIELD
TAMPICO OIL FIELD
PYRAMID HILL O.F.
ROUND MOUNTAIN OIL FIELD
FRUITVALE OIL FIELD
BAKERSFIELD
Edison
EDISON OIL FIELD
MOUNTAIN VIEW OIL FIELD
McKITTRICK FRONT OIL FIELDS
McKittrick
ELK HILLS OIL FIELDS
CANAL OIL FIELD
STRAND OIL FIELD
TEN SECTION OIL FIELD
CANFIELD RANCH OIL FIELD
COLES LEVEE OIL FIELD
Buena Vista Lake
BUENA VISTA LAKE GAS FIELD
PALOMA OIL FIELD
BUENA VISTA HILLS OIL FIELD
ARVIN OIL FIELD
Arvin
Recruit Pass
Fellows
Taft
Maricopa
Simmler
La Panza
TEJON RANCH FIELD
WHEELER RIDGE OIL FIELD
Grapevine

FIG. 1

STRATIGRAPHY

The main purposes of this paper are neither stratigraphic nor paleontologic, but a discussion of certain of the formations of the Southern Temblor Range seems necessary in order that later chapters be intelligible. The pre-Cretaceous crystalline rocks will be treated in a separate chapter, Cretaceous and Eocene strata are not exposed here, and Pliocene and later rocks are not pertinent to the main issue. Accordingly, the following statements are confined to the Oligocene and Miocene beds.

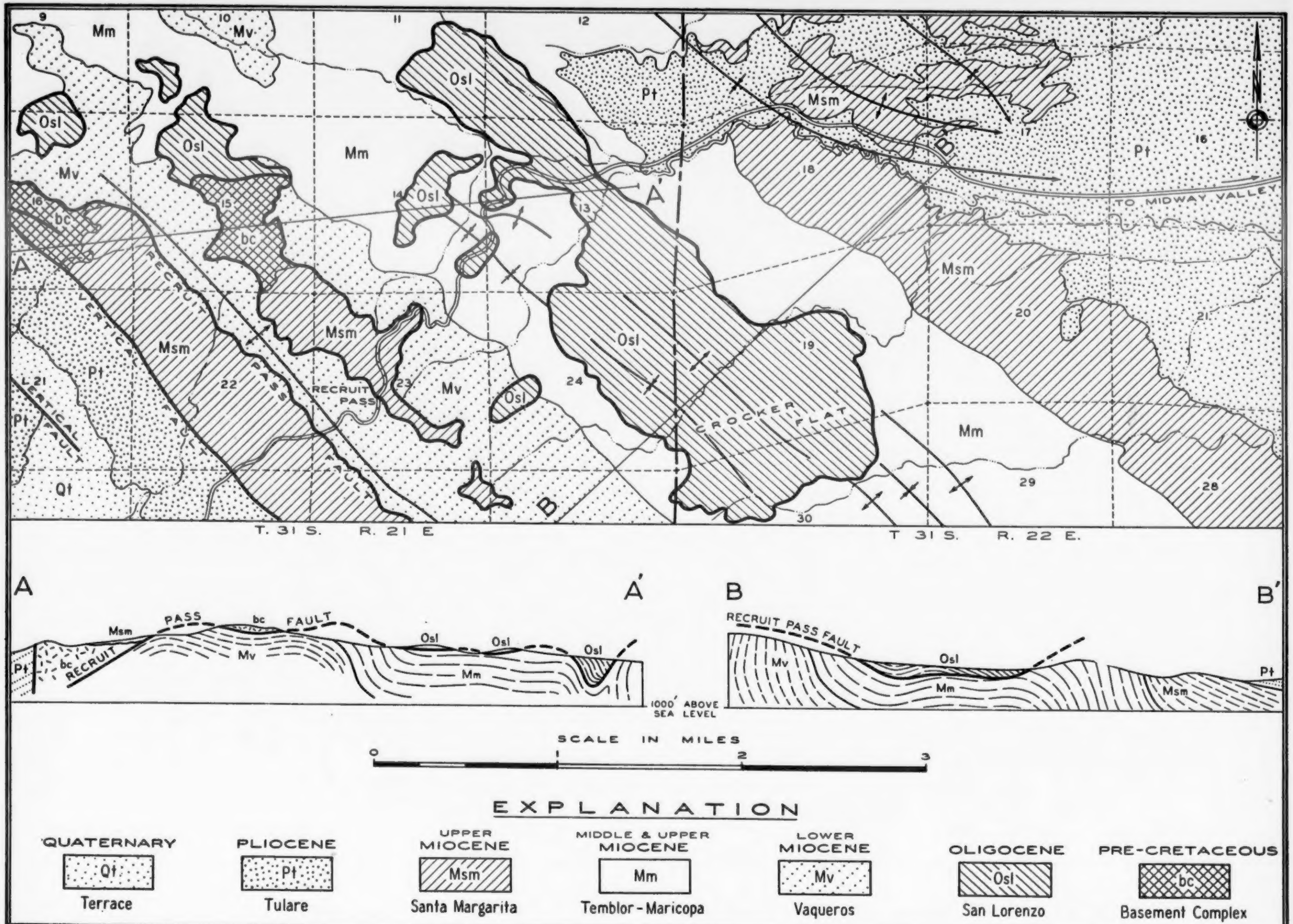
Vaqueros-San Lorenzo series (*Oligocene-lower Miocene*).—In the region of Crocker Flat, 6 miles southwest from McKittrick, a mass of chocolate-brown siltstone, approximately 1,000 feet thick, crops out in Secs. 19 and 30, T. 31 S., R. 22 E., and Secs. 11, 12, 13, and 24, T. 31 S., R. 21 E. This rock yielded a rather varied fauna, determined by Alex Clark as undoubtedly of San Lorenzo (Oligocene) age. It is shown as an inlier of Vaqueros (lower Miocene), in the midst of Monterey (middle Miocene) on the map of Arnold and Johnson (1910, Pl. 1), but, as will be shown later, it is actually an infolded outlying remnant of a thrust cover.

Immediately southwest is an outcropping band, about one mile wide, composed of buff and gray sandstones and brown siltstones with thin limestone beds extending along the crest and south flank of the range from the center of T. 31 S., R. 21 E., through Sec. 31, T. 31 S., R. 22 E., to Sec. 9, T. 32 S., R. 22 E. About 1,500 feet of these beds are to be seen here, the sandstones with base not exposed lying below, and being overlain by the siltstones which grade up into the Maricopa siliceous shales.

There is no direct faunal evidence as to the age of these beds, but from paleontologic evidence from other parts of this region coupled with lithologic and structural considerations, they are, in conformity with Arnold and Johnson (1910, Pl. 1) considered to be Vaqueros (lower Miocene).

Maricopa-Santa Margarita series.—Overlying the Vaqueros with what seems to be gradational contact, and cropping out in a band 2 miles wide along the northeast flank of the range is a mass of siliceous and foraminiferal shales, siltstones, and chert with minor amounts of limestone, aggregating approximately 5,800 stratigraphic feet. In this report these are called Maricopa, and are believed to represent middle Miocene, and perhaps a part of upper Miocene, time.

Overlying the more compact shales of the Maricopa on the northeast flank of the range are 2,700 feet of diatomites and "punky" shales,


TO MIDWAY VALLEY
RECRUIT PASS
CROCKER FLAT
RECRUIT PASS FAULT
VERTICAL FAULT
T. 31 S. R. 21 E
T 31 S. R. 22 E.
A
A'
B
B'
1000' ABOVE SEA LEVEL
SCALE IN MILES
EXPLANATION
QUATERNARY
Qt
Terrace
PLIOCENE
Pt
Tulare
UPPER MIOCENE
Msm
Santa Margarita
MIDDLE & UPPER MIOCENE
Mm
Temblor-Maricopa
LOWER MIOCENE
Mv
Vaqueros
OLIGOCENE
Osl
San Lorenzo
PRE-CRETACEOUS
bc
Basement Complex

containing the lenticular masses of coarse sand and very coarse conglomerate which are here described. In conformity with Arnold and Johnson (1910, Pl. 1), the writers have called these strata Santa Margarita, but, on the basis of study by Alex Clark, of a fairly rich fauna, the writers believe these beds to be definitely upper Miocene, and not, as they (1910, p. 56) and Pack (1920, p. 35 *et seq.*) concluded, upper middle Miocene.

Along the southwest flank of the range, from Sec. 7, T. 31 S., R. 21 E., southeasterly to Sec. 36, T. 32 S., R. 22 E., is a band, varying from a few hundred feet to more than one mile in width, in which are exposed sediments that the writers have referred to the Santa Margarita. The same peculiar types of rock that are found in the Santa Margarita of the northeast flank of the range, namely, diatomites and coarse sands and conglomerates, are found here. In certain of the areas of this band, isolated from the others by faulting, clastics crop out to the exclusion of diatomaceous sediments, but characteristic upper Miocene fossils were found in some of these isolated clastic masses, thus making the correlation appear secure for the whole.

Coarse clastics of lithology similar to the known Santa Margarita occur in isolated outcrops along the summit of the range, between Secs. 15 and 25, T. 31 S., R. 21 E. These are erosional remnants of a thrust cover, resting on Vaqueros strata, and are more fully described in a later chapter.

CRYSTALLINE ROCKS AND UPPER MIOCENE COARSE CLASTICS

Of the features of the Southern Temblor Range that deserve study, the two most spectacular are: (1) the crystalline rocks that occur on the summit and southwest flank, in the vicinity of Recruit Pass, in the midst of sediments of Oligocene and Miocene age, and (2) the coarse clastic material, including huge boulders of crystalline rocks, that occurs as lenticular masses in the fine, diatomaceous sediments of Santa Margarita age, on the northeast flank of the range.

Pre-Cretaceous crystalline rocks.—The earliest statement in geologic literature regarding the occurrence of ancient crystalline rocks in the Southern Temblor Range is by Arnold and Johnson, who said (1910, p. 87) that in Sec. 15, T. 31 S., R. 21 E.,

> Gravels and sands believed to belong to the McKittrick formation are involved in the intense faulting which has pushed a small block of pre-Cretaceous granite up through all the overlying sedimentary beds and brought it into contact with late Miocene deposits of the summit of the range.

The "McKittrick formation" of these authors in this area is believed

by the writers to be Santa Margarita, and their "granite" is actually a complex of crystalline rocks.

These crystalline rocks actually occur at two separate localities, the larger outcrop in Section 15 being on the summit of the range, whereas the smaller is on the southwest flank of the range, in the adjacent Section 16. Both are shown on the map of Arnold and Johnson (1910, Pl. 1). The summit locality is the outcrop of a thin, flat mass of gray, quartz-mica schist and white to bluish gray, coarse-grained marble. It is underlain by a layer of gouge and breccia, beneath which are sediments of Vaqueros age, and it is unconformably overlain to the south by fanglomerate believed to be of Santa Margarita age. The crystalline rocks, together with the fanglomerate, are believed to be an erosional remnant of the thrust cover of an important fault, which the writers have called the Recruit Pass fault. The smaller exposure on the west in Section 16 is the outcrop of a thin mass of schist, quartzite, and coarse-grained granodiorite, which is deemed to be part of the root zone of the same fault.

The metamorphic rocks appear to be certainly older than Cretaceous, because no such severely altered sediments are known in the Cretaceous in California. They may be much older because they resemble the ancient rocks of the Mojave Desert region (lower Paleozoic or pre-Cambrian), more than the Franciscan and Mariposa rocks (Jurassic and possibly Triassic) of the Coast Range and Sierra Nevada. The granodiorite is also of uncertain age. It may be the local representative of the post-Mariposa (late Jurassic) batholith of the Sierra Nevada, or it may be much older.

Lawson, in his description of the San Andreas rift, called attention to the fact that from the southern end of Carissa Plain to Bodega Head (north of San Francisco) granite exposures are wholly on the southwest side of the rift, save for one occurrence in Nelson Canyon, reported by Fairbanks, and stated (1910, p. 50): "The Rift in the Coast Ranges thus appears to serve as a line of demarkation between two somewhat contrasted geologic provinces."

Nelson Creek is a tributary of Big Sandy Creek, coming from the southeast to join the latter near the southeast corner of Sec. 17, T. 22 S., R. 13 E., about 12 miles northwest of Parkfield in eastern Monterey County. Throughout the greater part of its length the channel of Nelson Creek lies midway between the northeastern and southwestern bounding faults of the San Andreas Rift zone, as mapped by English (1918, Pl. XXVII), but in Sec. 25, T. 22 S., R. 13 E., its headwaters extend into the area immediately east of the rift, as shown on that map. It is probably in this headwater region that Fairbanks observed

(1893, p. 71) "in a small gulch which enters the canyon of Nelson Creek from the high ridge of metamorphic rocks on the northeast" a series of layers of crushed limestone, mica schist and green jasper, dipping 80° SW., terminating to the northeast against crushed sandstone and serpentine, and being marked at the southwest end of the described section in, and immediately adjacent to, Nelson Creek proper, by alternating bands of brecciated granite and limestone. This headwater area lies immediately northwest of the northwest corner of English's special map of the Parkfield area (1918, Pl. XXVIII), and about 2 miles, directly along the strike, from a sliver of "pre-Franciscan rock," shown by him as lying within the rift zone. From this it seems likely that Fairbanks' granite and limestone also lie within the rift zone, and not northeast as suggested by Lawson.

Accordingly, it is concluded that the Nelson Creek occurrence is not an exception to the rule that the ancient rocks do not crop out on the northeast side of the rift zone, and the sole exception recorded in geologic literature is that of the Recruit Pass area. Before developing this subject further, the point should be made that this rule should be recast to read: from the southern end of Carissa Plain north to Bodega Head no granitic or extensively and highly metamorphosed rocks are exposed on the northeast side of the San Andreas Rift zone, the basement rock exposed there being the Franciscan series. There are exceptions to this rule, but all of the exceptions known to the writers seem to be explicable in such ways as to permit the belief that everywhere along this stretch of the rift zone a considerable thickness of Franciscan lies between the ancient metamorphic rocks and granites and the Cretaceous-Tertiary sequence in the block on the northeast side of the rift zone. The known exceptions are the following.

1. Certain gabbros, quartz-diorites and quartz-gabbros that crop out in localities definitely northeast of the rift, such as the quartz-diorite at Gold Hill in the center of T. 24 S., R. 15 E., on the east side of Cholame Valley. These rocks are not known to be associated with widely and highly metamorphosed rocks, and may very well be phases of the basic intrusions that gave rise to the extensive serpentine masses seen in the Franciscan areas.

2. The blocks of crystalline rock, such as those mapped by English in the Parkfield area, some of which may be east of the rift zone, as shown on published maps, but which are possibly all actually within the rift zone.

3. The granodiorite and metamorphic rocks on the west flank and crest of the Temblor Range in the Recruit Pass region, which are definitely east of the rift zone.

Reed and Hollister speak of the basement rock of the Recruit Pass region as "interesting because it lies northeast of the San Andreas fault and is farther northwest than any other granitic outcrop near that fault and on its northeast side" (1936, p. 79).

According to the present writers' ideas of the mode of origin of the Recruit Pass thrust cover, the granodiorite and metamorphic rocks of the Temblor Range belong to the geologic province southwest of the San Andreas rift and came to their present position northeast of the rift through thrust faulting. They are hence no exception to Lawson's idea of the importance of the rift as a boundary between two contrasted geologic provinces. Further, if Reed and Hollister had known that these rocks are not part of the core of the range, but actually are parts of a mass thrust over the indigenous formations, they would doubtless have extended the southeastern end of their Northern Franciscan area (1936, Fig. 2) past the central part of the Temblor Range, to include all of the range. Indeed, the faulting and intricate folding of the entire Southern Temblor Range would seem to conform to the type of structure which Reed suggested (1933, p. 29) is to be expected in ranges having Franciscan cores.

Upper Miocene coarse clastics.—The Santa Margarita beds of the northeast flank of the range differ from the underlying Maricopa, not only in containing lenticular masses of coarse arkose sand and coarse arkosic conglomerate with boulders of schist, marble, sandstone, limestone and granite, many of the latter huge in size, but also in the character of its diatomaceous deposits which contain disseminated sand grains. Moreover, the fine-grained beds of the younger formation are generally of much lower density than most of the Maricopa shales.

Despite these characteristic differences, it is by no means easy to select a horizon for the contact between the two formations, and, once this horizon is selected in any particular section, it is a difficult task to trace it for any great distance. This, because the sandstones and conglomerates of the Santa Margarita occur in stout, lenticular masses, grading laterally into shales, and, also, because no stratigraphic plane is to be found, above which there is no dense shale of Maricopa aspect, and beneath which there are no "punky" shales.

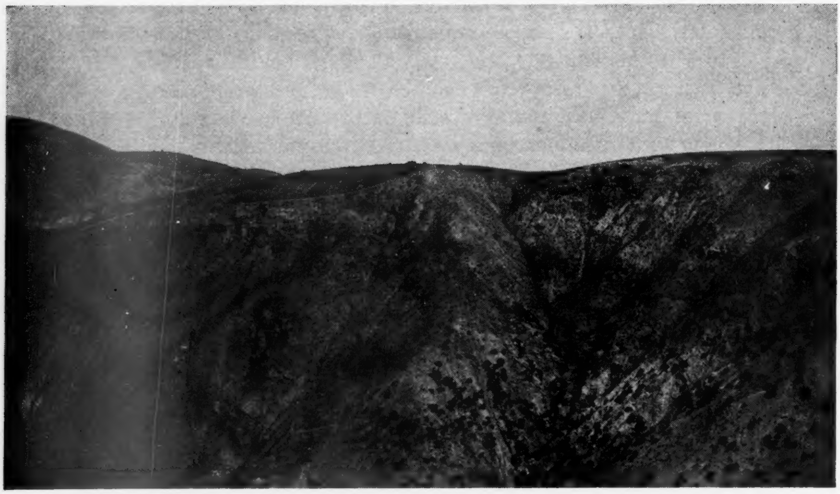
The thickest exposed section of Santa Margarita, composed of 2,700 feet of beds, is in Secs. 21 and 29, T. 31 S., R. 22 E., about 4 miles northwest of Fellows. It includes three bodies of arkose sand and conglomerate, and two bodies of "punky," diatomaceous shale. A thinner section, but one illustrating better the peculiar clastic deposits, is that exposed in Sec. 27, T. 32 S., R. 23 E., 5 miles southeast of Fellows, where there are 1,270 stratigraphic feet of diatomaceous

shales, containing, 400 feet from the top, a 10-foot bed of coarse conglomerate which is composed of subangular boulders of granodiorite (up to 3 feet in diameter), and smaller, angular boulders of dark gray, non-fissile, quartz-mica schist, and coarse-grained white marble, in a matrix of gray, arkose sand of medium to very coarse grain. Within $\frac{1}{4}$ mile in both directions along the strike from this locality, additional layers of the coarse conglomerate come in as lenticular masses within the upper 400-foot shale body.

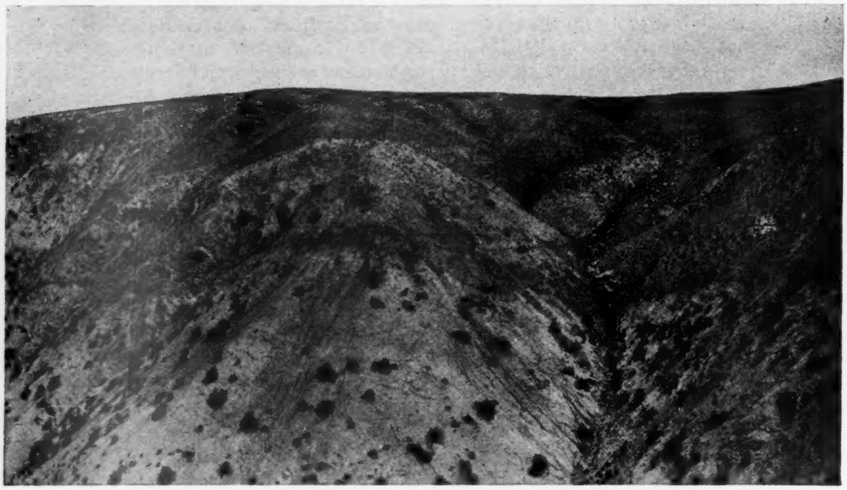
The alternation of strata of organic origin with coarse clastic deposits is particularly extraordinary in that there is no evidence of unconformity either at the base or within the Santa Margarita formation. This was recognized by Arnold and Johnson, who said (1910, pp. 70–71):

It is clear that the purely organic beds, since they contain little or no material of detrital origin, could only have originated far from shore or in deep water along the face of a steep escarpment at a distance from the influence of shore currents or of inflowing waters. It is equally clear that the coarse, usually subangular granitic bowlders and blocks which lie in immediate contact with or as lenses in the organic shales indicate conditions of deposition utterly dissimilar. Few of these blocks could have been transported by the measure of present-day evidence in the same region much more than 6 or 8 miles. Some of them, 12 or 15 feet in diameter, could hardly have been moved so far unless on a very steep gradient and by torrential volumes of water, which dumped their loads unassorted at the first convenient place. Such a condition is surely in sharp contrast with the evidence of tranquil accumulation of organic remains in the adjacent shales. This change did not happen once only, but many times, and it is difficult to conceive of the land and drainage conditions during the period. Except at one point, where a small mass of granitic rock has been faulted up into the Monterey and Vaqueros near White's camp, no granitics are exposed along the Temblor Range. The nearest known source for the bowldery lenses, then, is the Mount Pinos Range, which is fully 25 miles distant from the nearest exposures. The conformity between the Monterey shale and the Santa Margarita (?) does not suggest that the Monterey existed as a Mountain range during Santa Margarita(?) time. If the granitic conglomerate was derived from the Mount Pinos Range through the agency of torrential streams, the existence of such a range as a part of the old Mount Pinos Range must, however, be assumed. There still remains the possibility of the bowlders having been carried by moving ice, which, with its load of morainal material, originated in a possibly much higher Mount Pinos Range. No striae or other evidence of glaciation have been found on any of the blocks or cobbles in the series, however.

On the southwest flank of the range there are considerable areas in which the outcropping rocks have been correlated with the Santa Margarita, and the same age designation has been given to certain isolated masses of rock lying along the crest of the range. This region



A. General view, looking N. 6 W., from point on fault in SE. ¼, SW. ¼ of Sec. 15, T. 31 S., R. 21 E. Upper edge of dark band is upper limit of fault zone. Lower limit of fault zone is obscured by sliding débris of gouge and breccia. Bold outcrops above fault are of metamorphic rocks, and smooth slopes below are cut in Vaqueros sediments which dip steeply eastward.



B. Closer view of fault, immediately adjacent on right, to foregoing. Looking N. 55 E., in NE. ¼, SW. ¼ of Sec. 15.

FIG. 3.—Recruit Pass fault on southwest side of crest of range northwest of Recruit Pass.

is one of complex structure, and determinative fossils were found in only a few of the fault-separated blocks, but the correlation seems fairly secure because of the existence of the same rock types peculiar to the Santa Margarita of the northeast flank of the range.

In that part of the crestal and southwest flank region that is of particular interest in the present discussion, namely, that lying in the central part of T. 31 S., R. 21 E., the formation is composed exclusively of coarse detrital deposits, but diatomaceous beds occur farther south, on the southwest flank. In Secs. 15, 22, and 23 of this township, the large, erosion-isolated remnant of the thrust cover is composed of pre-Cretaceous metamorphic rocks, together with Tertiary sediments. At the northwestern end of the mass are brown and white, calcareous sandstones, with minor siltstone, which are assigned, questionably, to the Vaqueros-San Lorenzo series. They are in fault contact with the metamorphic rocks on the south. In the southeastern part of the mass, resting on the metamorphic rocks with depositional contact, are coarse detrital deposits which are assigned to the Santa Margarita on a lithologic basis and structural relationships. At the base is a member of white, pebbly sandstone, overlain by fanglomerate containing minor layers of coarse, massive sandstone. The predominant rock types found in the pebbles and boulders are granite, white marble, dark gray, non-fissile schist and gray quartzite. In the southeasternmost part of this same thrust-cover remnant, in the SE. ¼, Sec. 23, there are two exposures in which huge, rounded boulders of amygdaloidal basalt, up to seven feet in diameter, are present to the almost complete exclusion of the other types of rock. Arnold and Johnson (1910, p. 92) spoke of this material as the only occurrence of Tertiary igneous rock found in place in the Temblor Range, and described it as in part scoriaceous. It is in fact amygdaloidal, but the pitted character of the exposed surfaces appears to be due to the weathering out of the amygdules. The basalt is not in place, but occurs as boulders in a red, gouge-like material, along with rounded boulders of gray quartzite, granite, and white marble.

RECRUIT PASS FAULT

The mass of crystalline rock cropping out on the summit of the range in Sec. 15, T. 31 S., R. 21 W., was believed by Arnold and Johnson (1910, p. 87) to have been shoved up through the adjacent Vaqueros and Santa Margarita deposits, but this idea appears to be untenable. That this mass of metamorphic rocks, together with associated masses of Tertiary sedimentary strata, is actually an erosion-isolated remnant of a thrust cover, is shown by the following evidence.

1. Areal mapping, supplemented by observations made in trenches, shows that the base of the mass is nearly horizontal 2. Steeply inclined Vaqueros strata abut upon this gently inclined base from below. 3. The rocks of the overlying mass are separated from the underlying strata by a thick layer of gouge and breccia. The gouge, which is 20 feet thick in places, is composed of limonitic clay, carrying shale fragments, and it is overlain by as much as 6 feet of brecciated crystalline rock in those localities where the pre-Cretaceous metamorphic rocks form the base of the thrust cover.

After having learned the characteristics and significance of this gouge, it became possible to identify other thrust-cover remnants. On the basis of lithologic similarities, some of these remnants are believed to be of Santa Margarita age, and others are deemed Oligocene. The largest of the remnants, that which underlies Crocker Flat, is composed of beds of definite San Lorenzo (Oligocene) age. The fault plane underlying this isolated overthrust mass is folded in conformity with an anticline and syncline of the subjacent Miocene.

These thrust-cover remnants are believed to be erosion-isolated parts of a thrust-fault sheet which once covered a considerable area of what is now the Southern Temblor Range. Also considered a part of this thrust is the fault that extends from Sec. 7, T. 31 S., R. 21 E., for a considerable distance southeast. The plane of this fault dips southwest at angles varying from 45° to nearly vertical. Throughout much of its extent the rocks on both sides of this fault are sediments, those on the southwest side being the younger. These facts alone point to normal faulting. But in Sec. 16, T. 31 S., R. 21 E., there is a considerable mass of pre-Cretaceous crystalline rock on the southwest side of the fault, abutting on the Miocene strata of the northeastern side. This precludes normal faulting there and, as the possibility of reverse faulting is not excluded by the other facts, it is concluded that the whole fault is of reverse character. The name "Recruit Pass fault" has been given to this structural feature, after the near-by pass through which the road from San Joaquin Valley crosses the range to Elkhorn Plain.

Reasons for believing the thrust-cover remnants to be parts of the thrust sheet of the Recruit Pass fault are the following. 1. One of the two occurrences of ancient crystalline rocks in the Southern Temblor Range is in the gently inclined thrust-cover remnant on the summit of the range, north of Recruit Pass; the other is a short distance west, on the southwest side of Recruit Pass fault. It seems reasonable to believe these were once parts of a single mass. 2. The thrust-cover remnants must have "roots" somewhere and, of the known faults of

the region, the Recruit Pass fault is best fitted to serve in that capacity. 3. A simply curved plane may be passed through the bases of the thrust-cover remnants, and continued westward through an anticlinal curve, to join the Recruit Pass fault.

This anticlinal curve in the thrust plane is underlain by an anticlinal fold in the Miocene strata, suggesting folding of the fault plane after the thrusting was completed. Support for this idea is found in the Oligocene thrust cover of the Crocker Flat area, where folds in the fault plane overlie similar folds in the underlying Miocene beds.

The crystalline rock mass above the Recruit Pass fault in Sec. 16, T. 31 S., R. 21 E., comes to an end to the southwest against a northwest-trending, vertical fault, beyond which lie southwest-dipping Tulare (Pliocene) sediments. For this region, this vertical fault may be said to form the southwestern boundary of the Temblor Range. On its northeastern side are exposed the Santa Margarita and older rocks of the range, whereas for several miles to the southwest only Pliocene and younger sediments are seen.

This vertical fault is younger than the Recruit Pass fault, as it is known to cut it at several localities, and is older than the main San Andreas rift because it shows none of the evidences of recent movement seen along the latter. We believe that it may be regarded as the northeasternmost element of the San Andreas Rift zone, here 2 miles wide. It would follow from this that the crystalline rocks of the Recruit Pass fault are not indigenous to the province northeast of the San Andreas Rift zone.

The general character of the Recruit Pass fault suggests that its roots might be even as distant as the southwest side of the recently active San Andreas rift. As the evidence to decide this is not available, the writers can only conclude that the crystalline rocks are certainly not native to the province northeast of the broadly defined San Andreas Rift zone, and perhaps came from as far away as the southwest side of the strictly defined, recently active San Andreas rift.

Age of Recruit Pass faulting.—The fault block over-rode beds of Vaqueros, Temblor and lower Maricopa age. The overthrust block includes, in addition to the pre-Cretaceous crystalline rocks, strata of undoubted Oligocene and Santa Margarita ages. It should be noted in this connection that although no fossils were found in the coarse sediments that form remnants of the thrust cover along the crest and northeastern slope of the range, species indicative of Santa Margarita age were collected from strata of similar lithologic type that occur in the hanging-wall block of the fault along the southwestern flank of the range. From these considerations it is concluded that the major

part of the thrust movement occurred after the deposition of the latest Santa Margarita sediments of this region.

The thrust-cover remnants of the summit and northeastern flanks of the range are folded to a degree only slightly less than the subjacent Miocene strata, and perhaps slightly more than the Tulare (Pliocene) beds that overlie the Santa Margarita along the northeastern flank. This indicates that the thrust movement certainly took place before the major part of the folding of this region, and suggests the possibility that the thrusting may have occurred at some time before the beginning of the Tulare sedimentation.

From the foregoing it is concluded that at some date between latest Miocene and earliest Quaternary, the thrust sheet over-rode the middle and lower Miocene strata, which had not before that time been much affected by folding, and that during later periods of folding the thrust sheet has been folded along with the underlying beds. That the thrusting may have begun during Santa Margarita time is suggested in an hypothesis for the origin of the fanglomerate lenses of that age that is set out in the following chapter.

ORIGIN OF THE SANTA MARGARITA FANGLOMERATE LENSES

Along the northeast flank of Temblor Range the Santa Margarita formation rests conformably on the Maricopa formation. In some places this contact seems gradational from the denser shales of the older formation to the less dense shales of the overlying formation. At other localities the contact, though conformable, is marked by the presence of beds of coarse, arkosic, conglomeratic grit at or near the base of the younger formation, and by the presence of boulders of white marble and bluish black, non-fissile, quartz-mica schist, and huge boulders of coarse granite.

The conditions of shale deposition seem to have changed but little in passing from Maricopa to Santa Margarita time. But we must believe that the streams draining into the Miocene sea of this region suddenly began to carry huge boulders and coarse sand from a region which had hitherto not been sending detritus into the area of shale accumulation. The source region of the coarse detritus must have had a rugged topography. Excepting the possibility of glacial transport, this source area could have been at no great distance from the place where the coarse débris accumulated.

Such a source does exist near by, namely, the pre-Cretaceous crystalline rocks which crop out on the summit and southwestern flank of the range. Lending some credence to this idea of source is the presence, in boulders, of the fanglomerate lenses of peculiar rock types seen also in the summit mass of crystalline rock.

The idea of Arnold and Johnson (1910, p. 87) that the pre-Cretaceous crystalline rocks of this region are a part of the core of the range, pushed up through the overlying strata into contact with late Miocene deposits, was, as indicated by them (1910, pp. 70–71), incompatible with the idea of the source of the fanglomerate being in this crystalline mass. They were forced to look farther away for this source, namely, to the Mount Pinos Range, 25 miles south. This introduces another sort of difficulty, as the débris can hardly be supposed to have remained so coarse during such lengthy transport. As a last resort they mention the possibility of glacial transport, but point out that there is no direct evidence of such action to be found in the fanglomerate deposits.

These difficulties may be overcome by using considerations that arise from the discovery that the pre-Cretaceous crystalline rocks are not a part of the core of the Temblor Range, but are strangers from another province thrust over sediments indigenous to the range. The following hypothesis is offered for the origin of the fanglomerate lenses.

1. Movement along the Recruit Pass fault brought the crystalline rocks up, so as to expose them to erosion, at a date shortly before that represented by the datum plane selected as the base of Santa Margarita on the northeast flank of the range.

2. Sands and fanglomerates were deposited rapidly, and in considerable thickness, to form the lower part of the Santa Margarita deposits now seen on the summit and southwest flank of the range. During this period, what is now the northeast flank of the range was separated from the region of crystalline rock outcrop and coarse-detrital accumulation by a drainage divide, so that no coarse materials were carried into the area of Miocene shale deposition.

3. The thrusting continued in such a way that parts of the crystalline rock mass and (or) the coarse débris that overlay it were brought, from time to time and in only a few limited places, into the drainage province of the Santa Margarita shale deposition, thus furnishing the materials for the lenses of fanglomerate now found in that shale. At the same time thick deposits, for the most part of sand, were forming in the region that is now the southwestern flank of the range.

4. The thrusting was concluded either during or at the end of the upper Miocene, and the thrust sheet of crystalline rock and Oligocene and upper Miocene strata, which had come to rest on only slightly disturbed lower Miocene beds, was folded along with the underlying strata during the later movements that affected the range.

SUMMARY OF CONCLUSIONS

1. The crystalline rocks which occur in the region north of Recruit

Pass are not parts of the core of the Temblor Range, but are parts of the thrust sheet of the Recruit Pass fault which over-rode the Miocene strata of the range from the southwest.

2. These ancient rocks are strangers from another province thrust over the rocks native to the Temblor Range province; accordingly, their presence here does not strike at the fundamental truth of Lawson's statement: the San Andreas rift in the Coast Ranges is a line separating contrasted geologic provinces, in that from the southern end of Carissa Plain, northward to Bodega Head, granitic rocks are exposed only on the southwest side of the rift. Lawson mentioned one exception to this rule, not the Recruit Pass occurrence, but all such exceptions known to the writers are explicable in such ways as to permit the belief that under the Temblor Range, as well as elsewhere along the northeast side of the rift zone, in its course through the Coast Ranges, the ancient granitic and metamorphic rocks are separated from the overlying Cretaceous-Tertiary sequence by Franciscan rocks.

3. The Recruit Pass thrust sheet, consisting of the crystalline rock and strata of Oligocene and upper Miocene age, moved to the northeast over only slightly disturbed strata of lower and middle Miocene ages and was later folded into anticlines and synclines along with the over-ridden beds.

4. The age of the rocks affected by the faulting indicates that the major movement was at some time between latest Miocene and earliest Quaternary. The degree of folding of the thrust sheet, when compared with that of the Tulare (Pliocene of this region), suggests that the thrusting may have been pre-Tulare.

5. An hypothesis, offered for the origin of the lenses of coarse detritus which occur in the Santa Margarita shale of the northeastern flank of the range, includes the ideas that the Recruit Pass faulting began in upper Miocene time and that the rocks of the thrust sheet furnished the materials for the fanglomerate lenses.

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SEISMIC VELOCITY VARIATIONS IN SAN JOAQUIN VALLEY,[1] CALIFORNIA

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New York City

ABSTRACT

Velocity data have been obtained in approximately eighty wells in the San Joaquin Valley largely due to the efforts of the Coöperative Well Velocity Surveying Group, organized in July, 1938. Analysis of these data has revealed the existence of rapid lateral changes in velocity which fit into a regional pattern. The causes of the variations are discussed, also their effect on seismic-reflection mapping. Some methods for correcting reflection-survey data are considered.

INTRODUCTION

The past 2 years have seen a considerable development in the technique of applied seismology in California. The main trends and more obvious structures were discovered prior to that time so the reflection method has been used more for the purpose of precise detailed mapping of subsurface folding. For this work it is necessary to know, with considerable accuracy, the velocities in the sedimentary section. To obtain such data, the Coöperative Well Velocity Group was organized in July, 1938, with all of the major oil companies and geophysical companies as members. The past 2-year period was one of exceptional wildcat activity and observations were made in most of these wells, also in some proved fields, so that many velocity data were made available.

ACKNOWLEDGMENTS

Shortly after the writer began the preparation of this manuscript, Cecil H. Green, of the Geophysical Service Inc., gave him a copy of a report on the same subject which had been prepared for his company by Edgar J. Stulken in which many of the writer's findings were corroborated. This is not surprising in view of the fact that both had access to the same source data, although many of the concepts have seemed novel to persons not familiar with the results of these well surveys. Figures 7–13 of this article were generously contributed by the Geophysical Service Inc., from Stulken's report. The writer also wishes to record his appreciation of the services which D. E. Taylor as secretary of the Coöperative Well Velocity Surveying Group has rendered to all geologists working with seismograph data in California.

[1] Read before the Pacific Section of the Association at Los Angeles, California, November 8, 1940. Published by permission of The Texas Company. Manuscript received, January 13, 1941.

[2] The Texas Company, Room 2900, 135 East 42d Street.

IMPORTANCE OF VELOCITIES

Velocities, in some form, enter into all seismic calculations. When the precise distribution of velocities is known we can solve with a similar degree of accuracy the problems of finding the exact locations and slopes of any reflecting horizons. For some of these calculations the requirements as to accuracy of velocity determinations are rather critical. One fact which was discovered about the time the group was organized was the great importance of the horizontal or geographic gradient of velocity. Knowledge of the possible effect has of course been common for a long time. Westby[3] mentions it in 1931. Generally speaking, it is more important to know this gradient for mapping structure than it is to have a good average velocity curve. Its importance in this respect is analogous to the magnetic declination for surveys with the magnetic compass. A good many seismologists were probably as surprised to find the great range in velocity variation as Columbus was to find the great range in magnetic declination. As an illustration of the practical effect of lateral velocity changes, an uncorrected map of the Bakersfield region with contours on a 10,000-foot marker would contain, on the average, a cumulative error of more than 100 feet per mile. In some places the error would be 500 feet per mile.

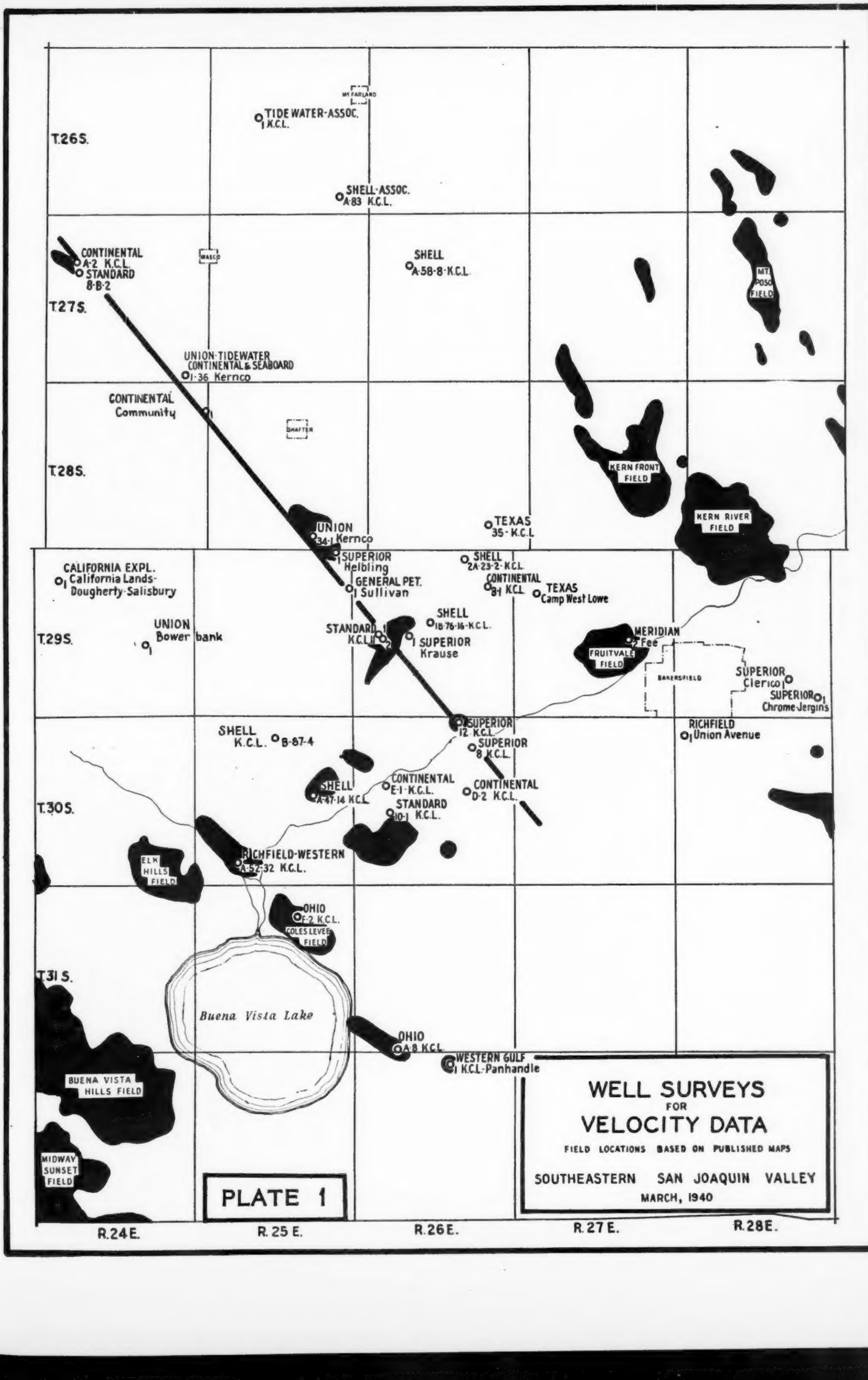
The original methods of finding velocities were by running long refraction profiles and by analysis of reflection records. These methods still have to be used where well data are unavailable. The limitations of these methods are well known and the results can not compare in accuracy with the information from well surveys.

In step with the increased data on the subject, there has been a great deal of study on the questions of how and why the velocities vary as they do and also on the problems of applying the data to structural mapping. This paper presents certain results of the independent research of two organizations, namely, The Texas Company and the Geophysical Service Incorporated. If other groups have different interpretations or methods we will be glad to have them outlined and discussed; it is for this purpose that this presentation is made. We may note here that the data for each particular well is the property of the organizations which drilled the well or paid for the surveys and we are indebted to these companies in presenting the data.

TYPES OF VELOCITIES

There are various types of velocities and it is best to give some definitions before starting the technical discussion. First of all, in re-

[3] G. H. Westby, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15 (1931), p. 1332.



McFARLAND
TIDE WATER-ASSOC. 1 K.C.L.
T.26S.
SHELL-ASSOC. A-83 K.C.L.
CONTINENTAL A-2 K.C.L.
STANDARD 8-B-2
WASCO
SHELL A-58-8-K.C.L.
T.27S.
MT POSO FIELD
UNION-TIDEWATER CONTINENTAL & SEABOARD 1-36 Kernco
CONTINENTAL Community
SHAFTER
T.28S.
KERN FRONT FIELD
KERN RIVER FIELD
TEXAS 35-K.C.L.
UNION 34-1 Kernco
SUPERIOR 1 Helbling
CALIFORNIA EXPL. 1 California Lands-Dougherty-Salisbury
GENERAL PET. 1 Sullivan
SHELL 2A-23-2-K.C.L.
CONTINENTAL 81 K.C.L.
TEXAS Camp West Lowe
UNION 1 Bower bank
T.29S.
STANDARD 1 K.C.L. 2
SHELL 18-76-16-K.C.L.
1 SUPERIOR Krause
MERIDIAN 2 Fee
FRUITVALE FIELD
BAKERSFIELD
SUPERIOR Clerico 1
SUPERIOR 1 Chrome-Jergins
SUPERIOR 12-K.C.L.
RICHFIELD 1 Union Avenue
SHELL K.C.L. B-87-4
SUPERIOR 8 K.C.L.
CONTINENTAL E-1-K.C.L.
CONTINENTAL D-2 K.C.L.
SHELL A-47-14 K.C.L.
STANDARD 10-1 K.C.L.
T.30S.
RICHFIELD-WESTERN A-52-32 K.C.L.
ELK HILLS FIELD
OHIO F-2 K.C.L.
COLES LEVEE FIELD
T.31 S.
Buena Vista Lake
OHIO A-8 K.C.L.
WESTERN GULF 1 K.C.L.-Panhandle
BUENA VISTA HILLS FIELD
MIDWAY SUNSET FIELD
WELL SURVEYS FOR VELOCITY DATA
FIELD LOCATIONS BASED ON PUBLISHED MAPS
SOUTHEASTERN SAN JOAQUIN VALLEY
MARCH, 1940
R.24E.
R.25 E.
R.26E.
R.27E.
R.28E.

PLATE 1

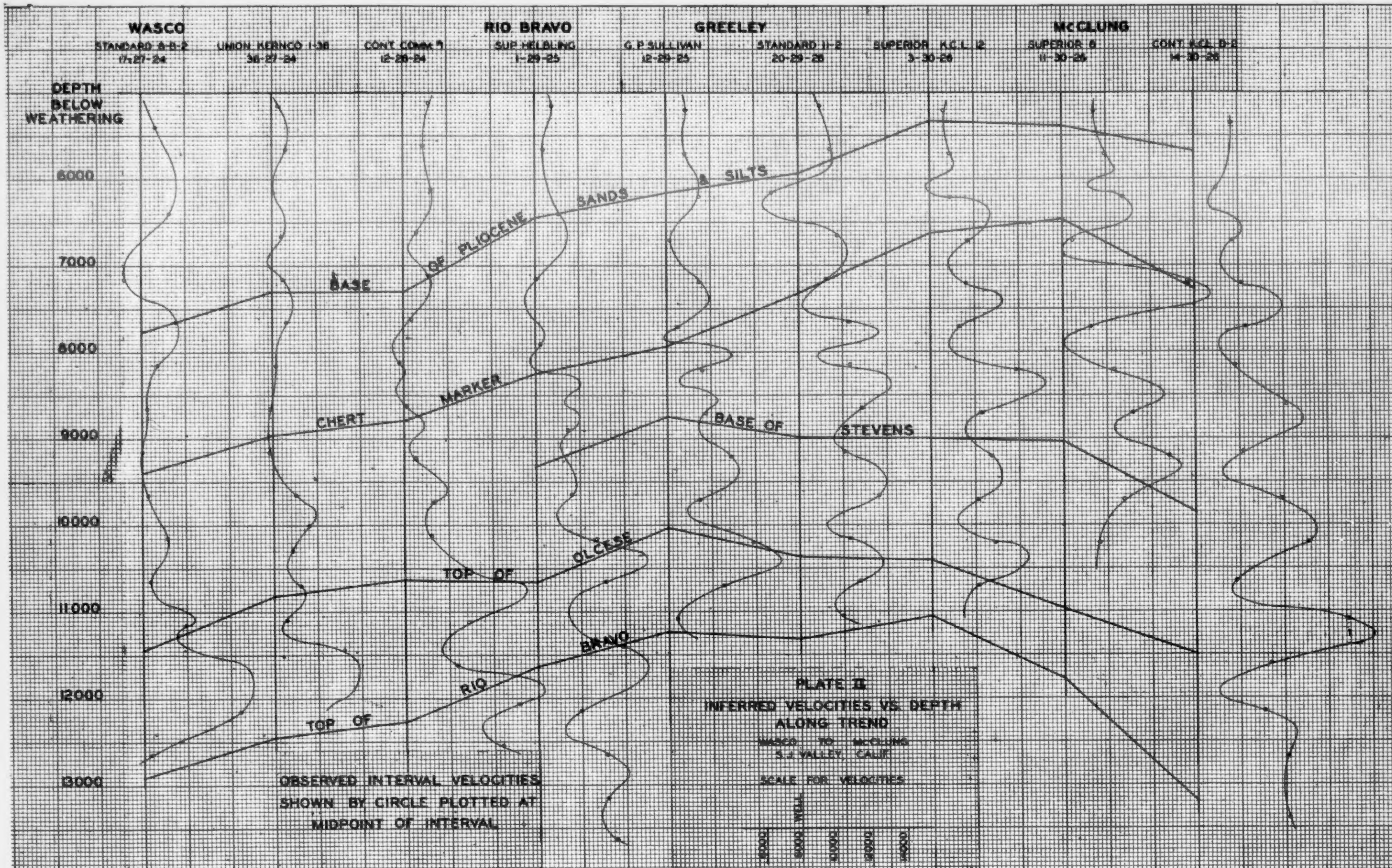
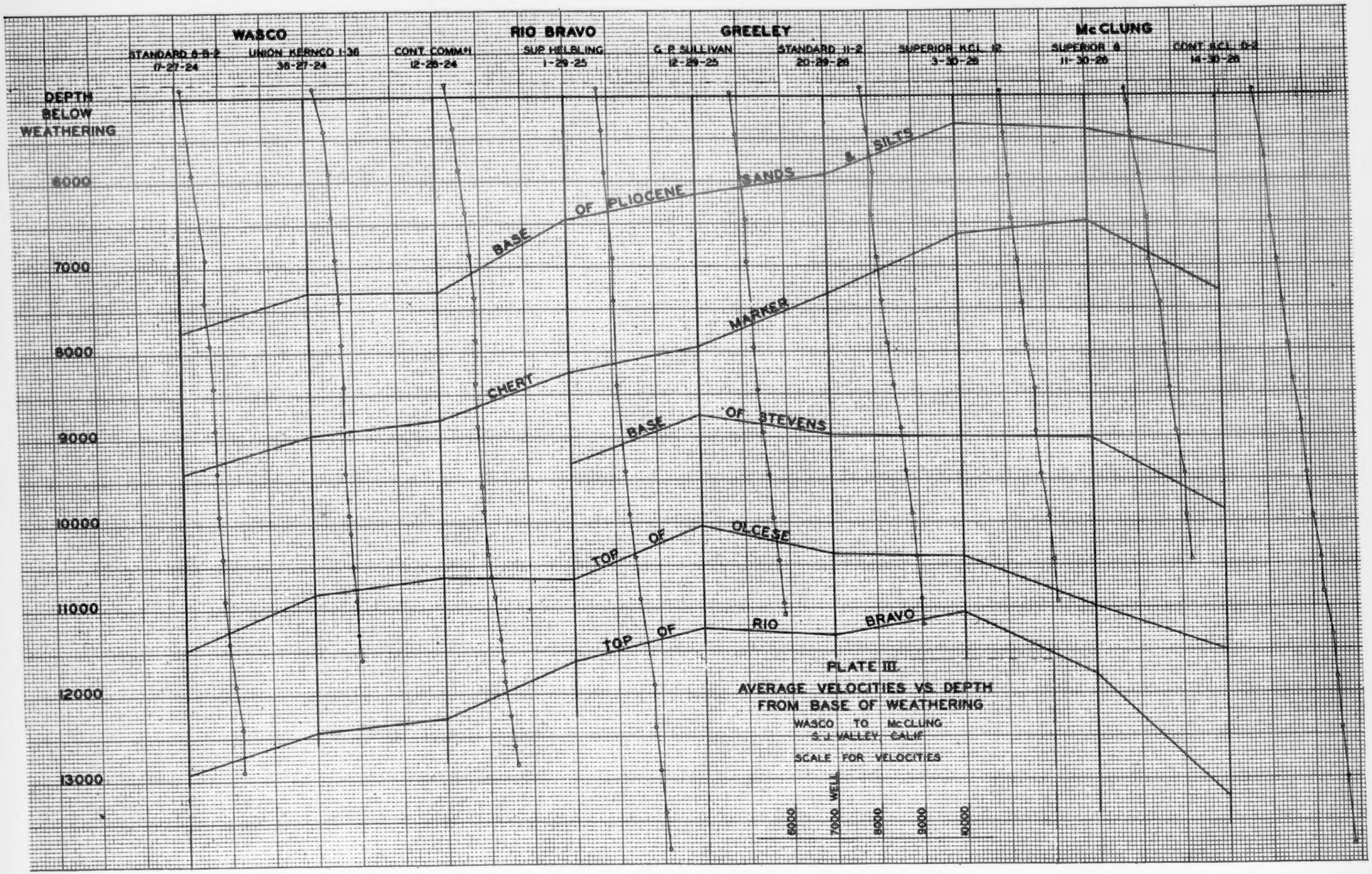


PLATE II
INFERRED VELOCITIES VS. DEPTH
ALONG TREND
WASCO TO McCLUNG
S. J. VALLEY, CALIF.

flection work we are concerned only with longitudinal velocities. The longitudinal velocity probably varies considerably with the frequency of the wave but this effect is ignored in the discussion. The fundamental type is the instantaneous velocity. This is the kind you read on the speedometer of your car. When the word velocity is used without qualification this kind is meant. Another is average velocity or overall velocity. It is found by dividing the total distance between two points by the total elapsed time. In general usage we take the straight-line distance between the points although we may know the actual path to be somewhat different. A third kind of velocity is the interval velocity. This is the average velocity between points fairly close together, say at 500- to 1,000-foot intervals, a kind of hybrid velocity. This is the kind that policemen measure when they set a speed trap and is the closest we can get, by present methods, to the true instantaneous velocity. In Plate I are shown the locations of a number of wells in the southeastern San Joaquin Valley. Plate II shows the inferred instantaneous velocities along a line of wells. There is no exact method of finding the velocities from the interval velocities, the only restriction being that the average velocities for the intervals must be the same as the determinations. The circles which represent the interval velocities are plotted at the midpoints of the interval. The velocity curve in most cases has been passed through the circles but this is not necessary. No claim for great scientific value can be made for the representation but it may contain suggestions to others who like to play with the subject. Drawing these curves is an occupation akin to doodling. Scientifically it is about on par with the occupation of drawing subsurface maps on luncheon tablecloths. It does however give one possible interpretation which may serve as a basis for discussion. If we could actually get a continuous measurement of the instantaneous velocity as it varies with the depth we would advance the science of seismology a great deal. The best present method is the use of a number of closely spaced detectors during well shooting. A spacing of 200 feet has been tried by one company in a number of wells. To be really satisfactory the spacing should be cut down to a 5- or 10-foot interval between detectors, a spacing comparable with that between Schlumberger electrodes. At present we have no equipment which could be used with such close spacing, and it would be expensive and difficult to develop. New cables, timing methods, and even new means of producing seismic energy might be necessary. It is believed that the results would be greatly worth while and that methods could be developed on a coöperative basis by an organization similar to our Well Velocity Group. We might then expect to find answers to many important problems.


WASCO
RIO BRAVO
GREELEY
McCLUNG
STANDARD 6-B-2
17-27-24
UNION KERNCO 1-36
36-27-24
CONT. COMM'H
12-28-24
SUP HELBLING
1-29-25
G. P. SULLIVAN
12-29-25
STANDARD 11-2
20-29-28
SUPERIOR K.C.L. 12
3-30-28
SUPERIOR 6
11-30-28
CONT. K.C.L. D-2
14-30-28
DEPTH
BELOW
WEATHERING
6000
7000
8000
9000
10000
11000
12000
13000
BASE OF PLIOCENE SANDS & SILTS
CHERT MARKER
BASE OF STEVENS
TOP OF OLCESE
TOP OF RIO BRAVO
PLATE III
AVERAGE VELOCITIES VS DEPTH
FROM BASE OF WEATHERING
WASCO TO McCLUNG
S. J. VALLEY, CALIF.
SCALE FOR VELOCITIES
6000
7000 WELL
8000
9000
10000

One of the problems is the correlation of reflecting horizons with lithology. We could compare the velocity curve with the resistivity and self-potential curves of the electric logs. We might even find a useful new method of well correlation, methods of locating faulting by finding induration, or other elastic effects. We would certainly locate new markers in the thick shale bodies such as the Reef Ridge or McLure shales since we get reflections from places in the section where no visible lithologic breaks can be observed.

Another problem about which we know practically nothing at present is how the velocity varies with the frequency of the energy. By analogy with light we may expect considerable variations in sound or seismic velocities. We would then expect to find the various sedimentary strata to reflect the different frequencies in different manner, and may get an explanation of how the reflecting power of a bed changes laterally.

We may also expect to find out a great deal about the character of the seismic impulse, and how it changes with depth. What the absorption coefficients are for the various frequencies and why the deeper reflections have in general a longer wave length. We may find the solution to such questions as the possible resonance of certain strata.

Both of the contributing organizations spent a great deal of time in trying to make definite correlations between seismic velocity and lithology, age, and depth of sediments. Other organizations doubtless did likewise.[4] The purpose was to find, if possible, a synthetic method of producing velocity curves from electric logs, core descriptions, and well correlations, without the necessity of making observations in a well. If it had been possible we could then fill out our velocity maps and correct our surveys without having to await the chances that wells would be drilled in desirable locations. The work was not all wasted but no one can yet definitely predict velocities without well shooting.

CAUSES FOR VELOCITY VARIATION

These investigations have been successful in a qualitative but not a quantitative way. So many factors influence the velocity that it is difficult to isolate the influence of any separate one, and so little is known about many of them that we can only surmise their presence.

The best that can be done is to divide them into a number of groups and then determine the tendency of the group influence. In this way we may say that the following groups have clearly defined influences.

[4] See W. Hafner, "The Seismic Velocity Distribution in the Tertiary Basins of California," *Bull. Seis. Soc. America*, Vol. 30, No. 4 (October, 1940), pp. 309–26.

(1) *Depth.* This includes associated factors, as temperature, pressure, compaction, and density
(2) *Geographical location.* This includes such regional phenomena as metamorphism, severe folding, regional variations in lithology, and large-scale structure
(3) *Lithology.* This includes mineralogical composition, size distribution, porosity, interstitial fluids, and degree of cementation of the sediments
(4) *Structural position (local).* The influence of position with respect to local uplift
(5) *Geological age*
(6) *Miscellaneous and accidental factors.* This includes faulting and obscure local phenomena, anisotropy, and dispersion

Velocity is definitely a function of depth. The precise manner in which depth and associated factors influence the elastic constants of rocks is not known, but in none of the wells has a negative coefficient of increase with depth been found when all observations are included. The velocity decreases with depth only for limited distances.

Velocity is a function of geographical location. In the San Joaquin Valley it will be noted that the velocities for corresponding depths or for corresponding reflection times are conspicuously higher near the margins of the valley than in the central portions. Reverse local trends in this connection are as limited as the reverse trends in the case of average velocity increase with depth. This regional velocity distribution shows such noticeable similarities to the general structural picture of the valley, that it is tempting to say that low velocities are merely a correlative of structural basins or areas of thick Pliocene deposition. However, one of the deepest of these basins, which lies at the southeast end of the valley, between Elk Hills and Wheeler Ridge, is not a region of correspondingly low velocities. Stronger regional influences than mere structure must be looked for here, influences which the writer believes may best be described as regional metamorphism. In fact the elastic characteristics of standardized types of sandstone and shale might well prove to be as sensitive indices of metamorphism as the fixed-carbon ratios of carbonaceous deposits.

Velocities vary with the lithologic character of the sediments. The range of lithologic variation in California is, however, greatly limited. High-velocity strata, such as limestone and salt, are conspicuously absent. Shales, particularly diatomaceous shales, have the lowest velocities. Sandstones, especially well cemented ones, have higher velocities. The ill-sorted, low-porosity, continental facies sediments, typical of the Chanac and Kern River formations, appear to have exceptionally high velocities. Mineralogical composition in clastic sediments appears to play a less important rôle in determining elastic properties than other factors such as porosity, grain-size distribution, and cementation. These factors are unfortunately not very amenable to rigorous classification and measurement.

That interstitial fluids influence velocity is seen in the variations

of the depth of the weathered layer with similar variations in the depth of the ground-water table. There is no information at present which would indicate that oil or gas accumulations have any important effect on velocities.

The lithologic variation makes the velocity an irregular or even discontinuous function of depth, which in turn is the reason that the reflection-seismic method can be used to outline structure. That the range of velocity variation is rather limited is the reason for the difficulties of carrying correlations for long distances. There is one main exception. The reflection from the sedimentary-basement contact has been carried rather widely in some places but even so there are various inconsistencies. This has been explained by assuming the existence of a fossil weathered zone.

There is a suggestion that velocities may be higher above folded structures than off structure. Plate III may be examined in this connection. The effect does not appear very great but an examination of the regional maps shows that the Greeley-Rio Bravo-Wasco trend has higher velocities than normal for its position in the valley. The effect is probably greater in the case of Kettleman Hills, although further control is needed. This would be in line with the report that velocities above Gulf Coast salt domes are higher than normal.[5] The San Joaquin Valley structures represent relatively a much smaller structural upthrust than the Gulf Coast salt domes. The effect of structure is probably composite. The lithologic distribution is changed, and the sediments which are uplifted may have undergone an irreversible change due to deep burial or prolonged pressure.

The effect of the geologic age of sediments is expressed in two ways. First the older sediments are relatively more deeply buried and hence have greater velocities due to the depth effect. Again the lithology varies with geologic age, the Pliocene, lower Miocene, and Eocene strata are notably sandy; whereas the upper Miocene, Oligocene, and uppermost Cretaceous sediments are much shalier. When these influences are eliminated it does not appear that mere age of the strata has any demonstrable effect.[6] A comparison of the velocities in the California Exploration Company's Salisbury well with those observed in the Shell Oil Company's San Emigdio well is rather illuminating. These wells, a little more than 30 miles apart, penetrate sediments of

[5] E. E. Rosaire and J. L. Adler, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18 (1934), p. 127.

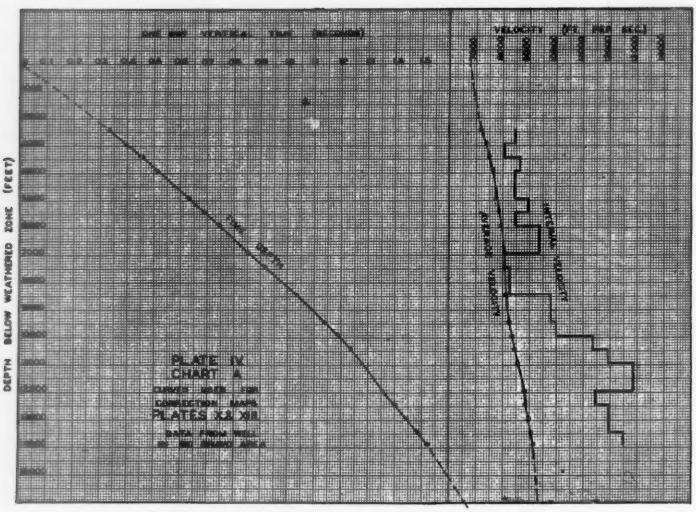
[6] This opinion appears to conflict with published data. See B. B. Weatherby and L. Y. Faust, "Influence of Geologic Factors on Longitudinal Seismic Velocities," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19, No. 1 (January, 1935), pp. 1–8. It does not appear, however, that regional influences were given much consideration.

practically the same age at corresponding depths, yet the depths for the two-second reflection time are respectively 6,921 feet and 9,415 feet.

Variation of velocities due to unknown factors have been noted in some local areas. In some places faulting is suspected or assumed. A great deal of research still remains to be done, particularly on the effects of dispersion, absorption, and anisotrophy.

USE OF ANALYTICAL EQUATIONS

Reflection calculations are concerned with finding the depth and position of the reflection surface and the amount and direction of the



dip. For flat beds the depth equals half the reflection time multiplied by the average velocity. For sloping beds the formulas become more complicated depending on how the velocity varies with depth. The amount of slope depends not on the average velocity but on the instantaneous velocity. Besides these calculations we have to take into account the lateral gradient which may involve corrections of several degrees. For any of these purposes it is convenient to have the velocity data in the form of analytical equations.

It would be possible to find equations to fit the curves illustrated in Plate II or for that matter any set of similar data. It would, however, be a great deal of trouble to do so, more than the data or their application warrant. There necessarily is some approximation in the

use of velocity data and the general opinion appears to be that some of the simpler curves can be made to fit sufficiently well. Two curves which appear to answer the purpose are: the linear increase of velocity with vertical reflection time, and the linear increase of interval velocity with depth. Both equations may be fitted to data by using least squares. These equations give the simplest of curved paths, namely, cycloids and circles. The degree of fit may also be determined rather simply. For the linear increase of average velocity with time the average coefficient of correlation for data from seventy wells appears to be around 0.98, in other words a fit of 98 per cent accuracy. The worst fitting set of data gave a fit of 89 per cent. Plate IV shows data from a deep typical well.

REGIONAL VELOCITY VARIATION

The regional or lateral variation of velocities in the San Joaquin Valley is best presented by maps. We can use several methods of illustration as follows.

(1) Velocities from the base of weathering to a given depth
(2) Velocities from the base of weathering to a given stratigraphic horizon
(3) Velocities from the base of weathering to a given reflection time
(4) Times from the base of weathering to a given depth
(5) Times from the base of weathering to a given horizon
(6) Depths from the base of weathering to a given reflection time.

Several maps of these types are presented here (Plates V, VII, IX, and XII). Plate V goes beyond the observed data to some extent. It is therefore partly an interpretation rather than a precise factual representation. Velocity data in some marginal areas were extrapolated so that the depths shown in these places are beneath the sedimentary blanket although representing the extrapolated tendencies of velocity increase with depth which were observed wholly within the sediments. The bowing of the contours around Kettleman Hills North Dome is partially an assumption which remains to be established by further well data.

METHODS OF CORRECTING

The effect of a horizontal gradient is that structures are mapped on a series of warped surfaces as datums. The maps showing depths for different reflection times represent such surfaces. Plate VI shows the effect of velocity gradient on the plunge of the Wasco-Greeley trend. These maps suggest immediately one way of making corrections, namely, by a set of depth-correction maps similar to isopach maps. The method is not quite as simple as it might seem. We could not use the map for the two-second reflection time for the Stevens

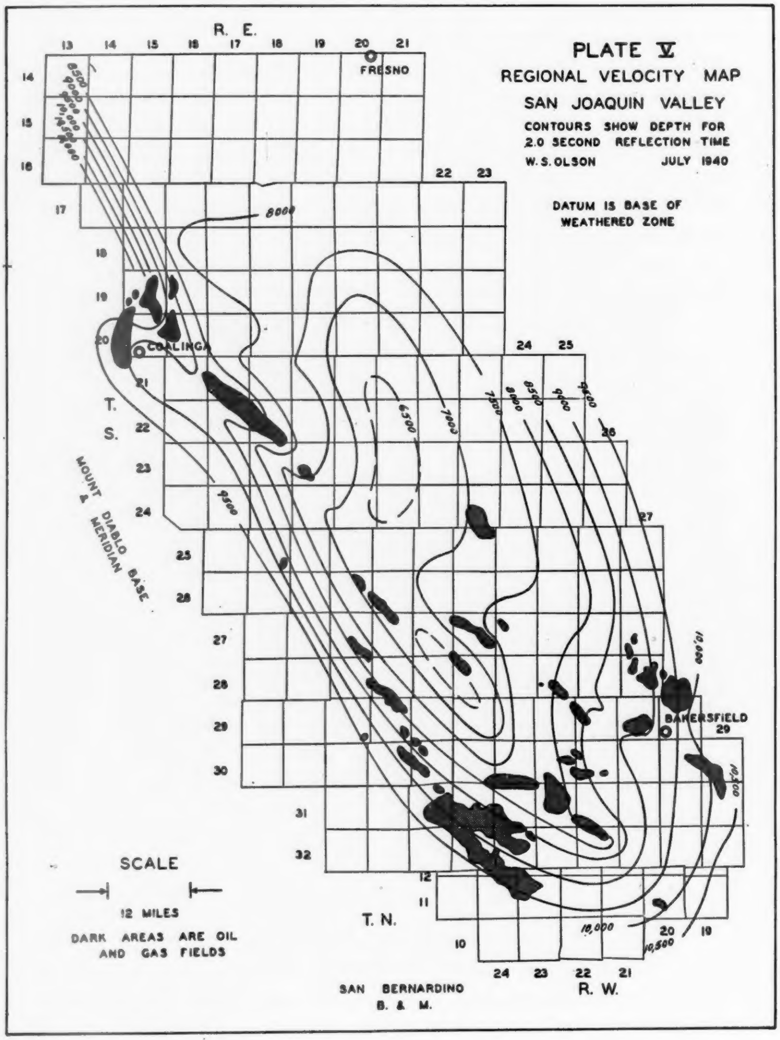


PLATE V
REGIONAL VELOCITY MAP
SAN JOAQUIN VALLEY
CONTOURS SHOW DEPTH FOR
2.0 SECOND REFLECTION TIME
W. S. OLSON JULY 1940
DATUM IS BASE OF
WEATHERED ZONE
R. E.
T. S.
FRESNO
COALINGA
BAKERSFIELD
MOUNT DIABLO BASE & MERIDIAN
SCALE
12 MILES
DARK AREAS ARE OIL
AND GAS FIELDS
T. N.
SAN BERNARDINO
B. & M.
R. W.
8000
6500
7000
7500
8000
8500
9000
9500
10,000
10,500

sand except along the line where this sand occurs at the two-second reflection time. Where the sand is deeper or shallower a different set of corrections must be applied. In other words, we must have the depth to the Stevens sand in order to know what corrections to apply; like the business of the hen and the egg you have to have the one to get the other. It is really not as bad as that; we can take an approximate depth such as would be found from Plates VIII and XI which merely represent interpolation from a set of well data and construct

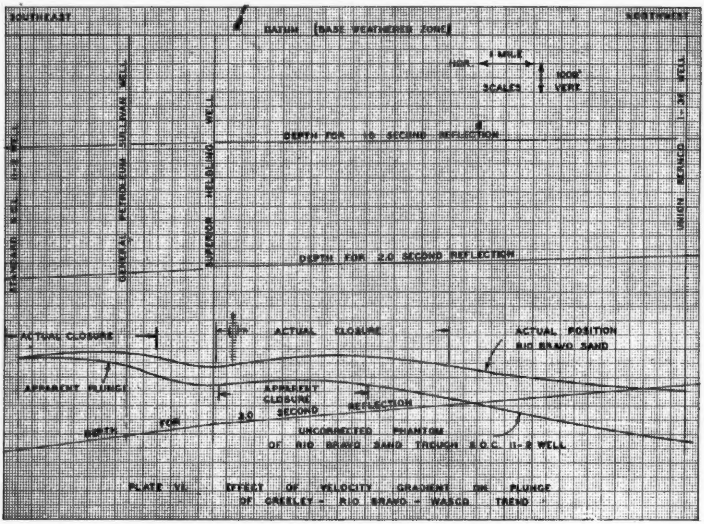


PLATE VI. EFFECT OF VELOCITY GRADIENT ON PLUNGE OF GREELEY - RIO BRAVO - WASCO TREND

a depth-correction map or isopach map like Plate X. The zero correction contour shows the location of the line where the velocity curve used actually coincides with the average velocity to the depth of the sand. Stulken has constructed these illustrative maps for the Stevens and Rio Bravo sands (Plates X and XIII). It must be noted that in this method it is necessary to construct three maps for each horizon to be corrected, an original structure map, an isopach map, and the final structure map. These maps are based on the velocities shown in Plate IV, Chart A, which is that of a deep typical well in the area.

There is another method by which the slopes may be corrected independently of any horizon if the velocity gradient is known. It can all be done neatly with equations, but the sections must be redrawn whenever new velocity data are found which upset the original

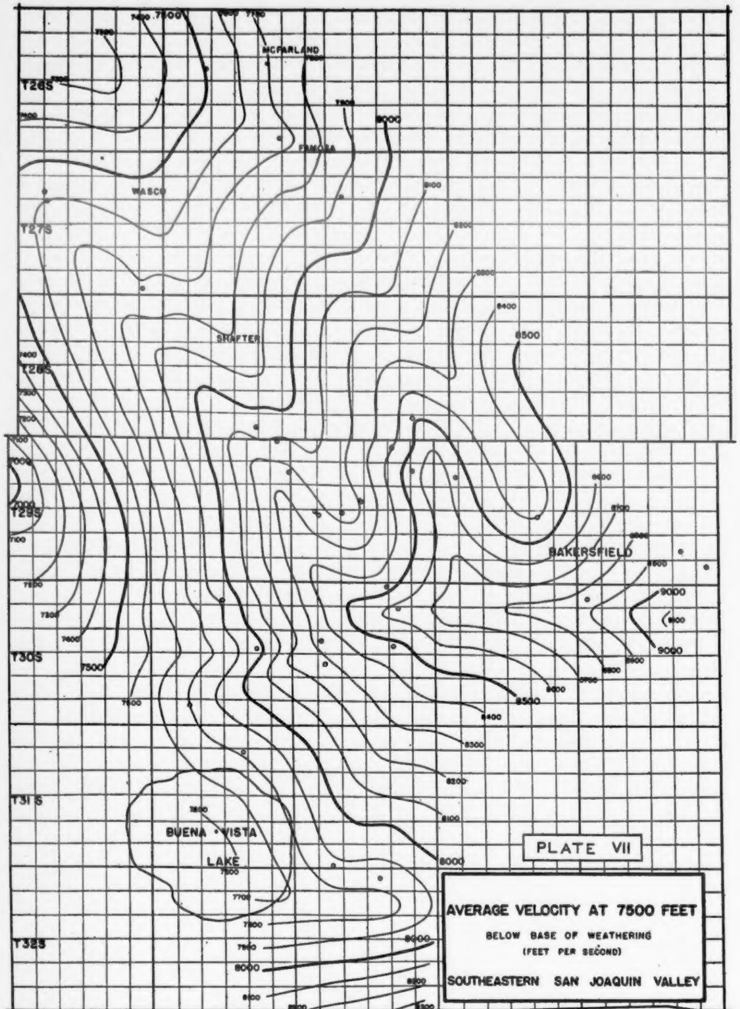


PLATE VII

AVERAGE VELOCITY AT 7500 FEET

BELOW BASE OF WEATHERING

(FEET PER SECOND)

SOUTHEASTERN SAN JOAQUIN VALLEY

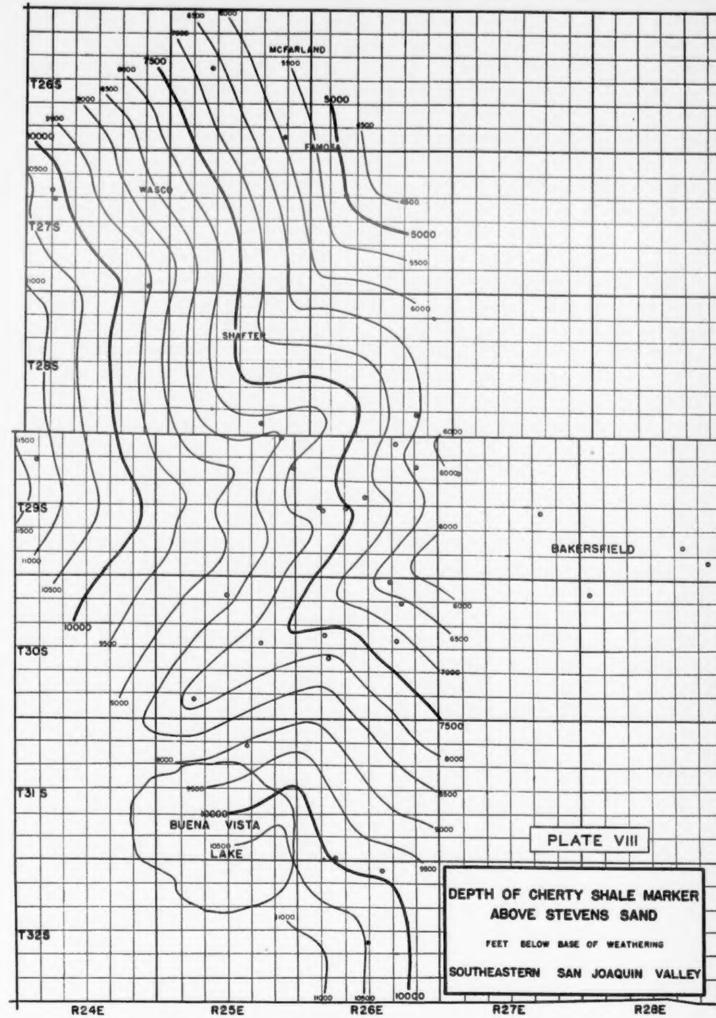


PLATE VIII

DEPTH OF CHERTY SHALE MARKER ABOVE STEVENS SAND

FEET BELOW BASE OF WEATHERING

SOUTHEASTERN SAN JOAQUIN VALLEY

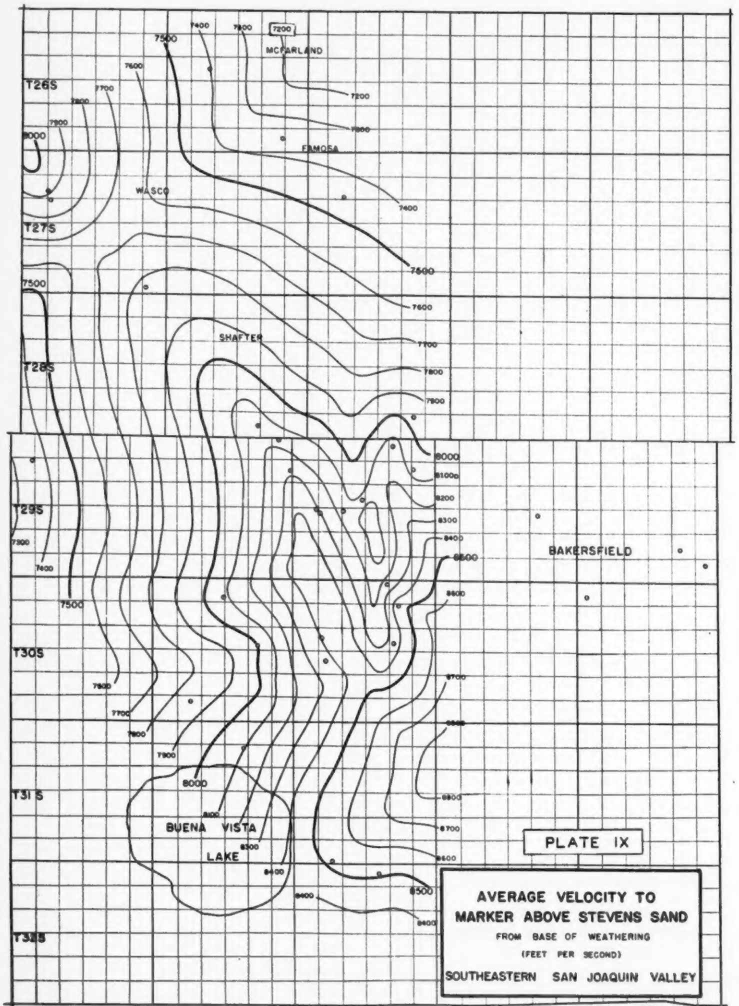


PLATE IX
AVERAGE VELOCITY TO
MARKER ABOVE STEVENS SAND
FROM BASE OF WEATHERING
(FEET PER SECOND)
SOUTHEASTERN SAN JOAQUIN VALLEY
MCFARLAND
FAMOSA
WASCO
SHAFTER
BAKERSFIELD
BUENA VISTA
LAKE
T26S
T27S
T28S
T29S
T30S
T31 S
T32S
R24E
R25E
R26E
R27E
R28E

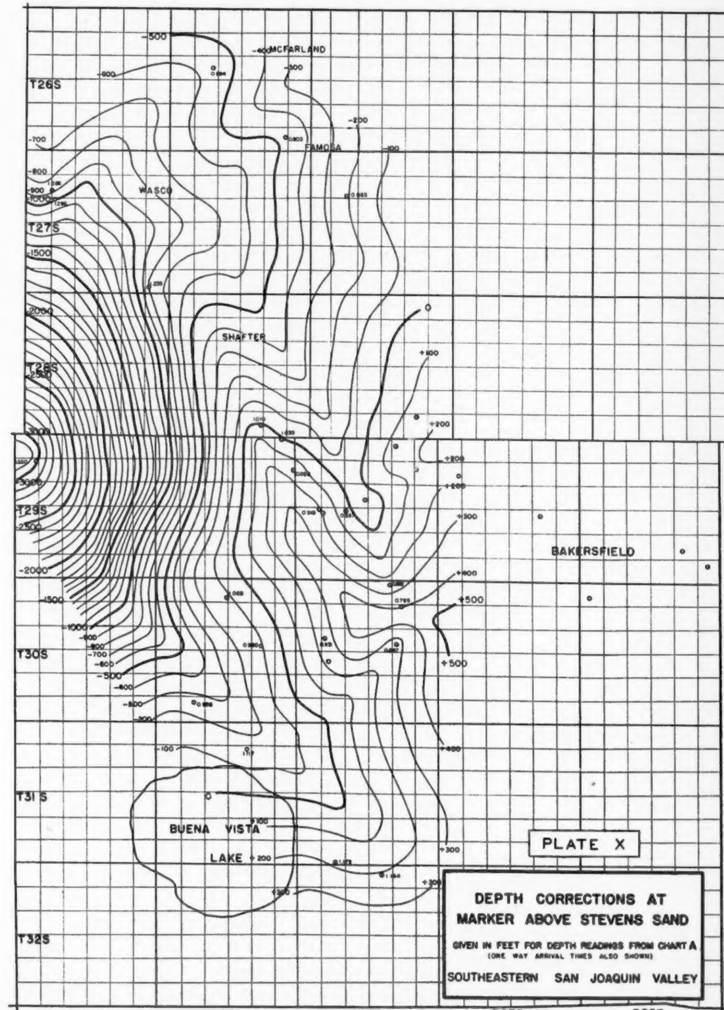
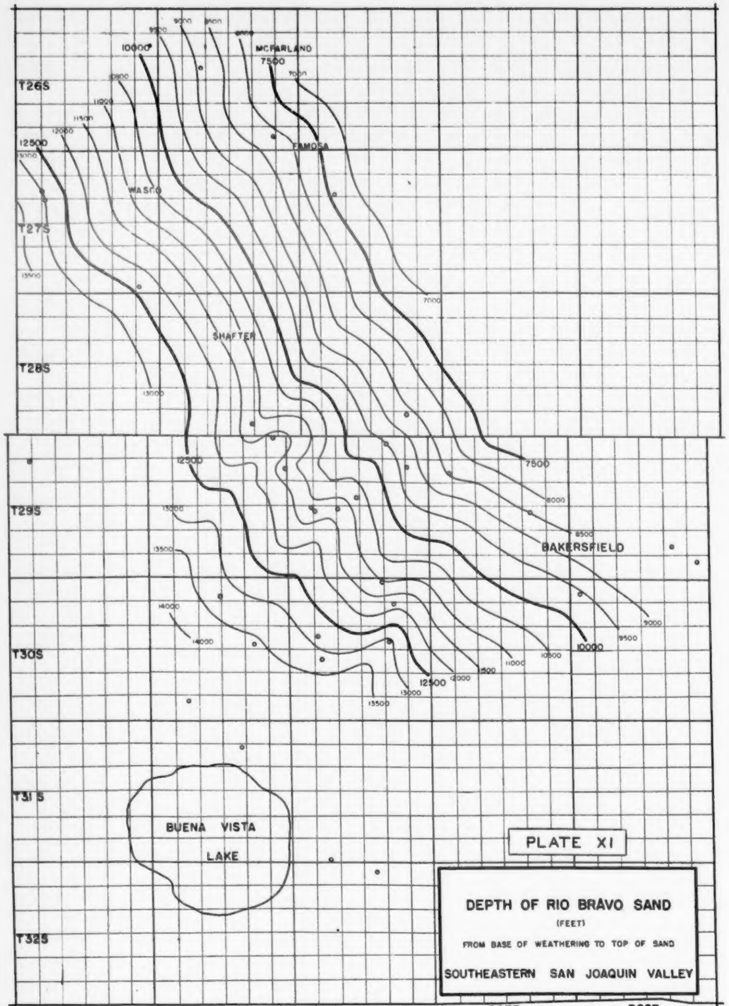
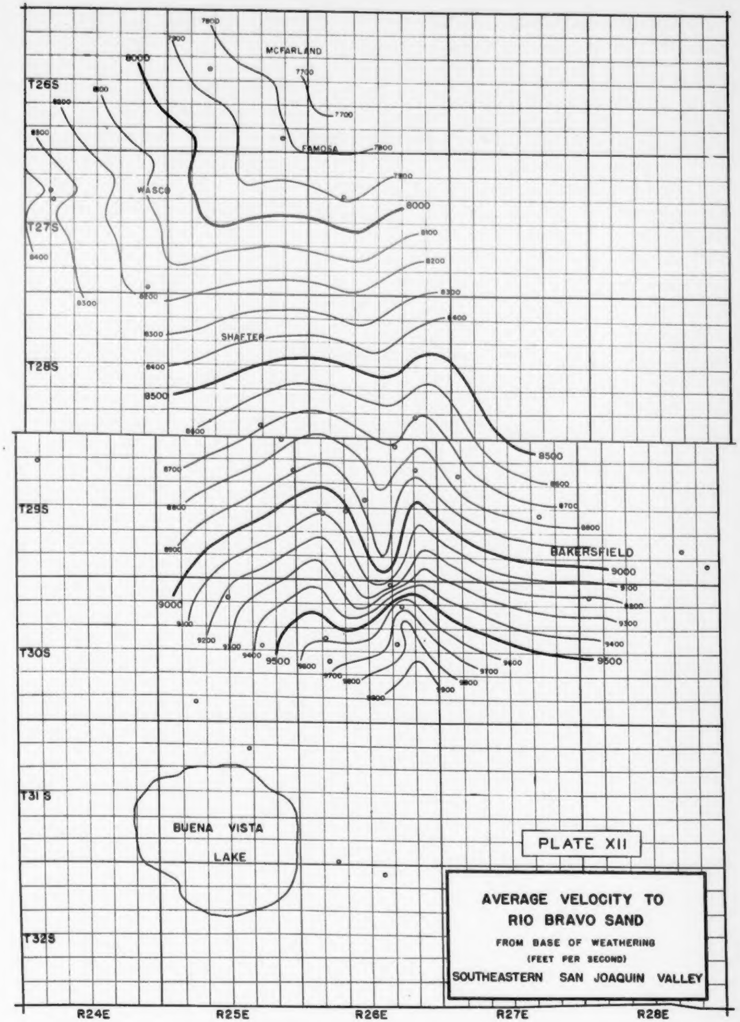
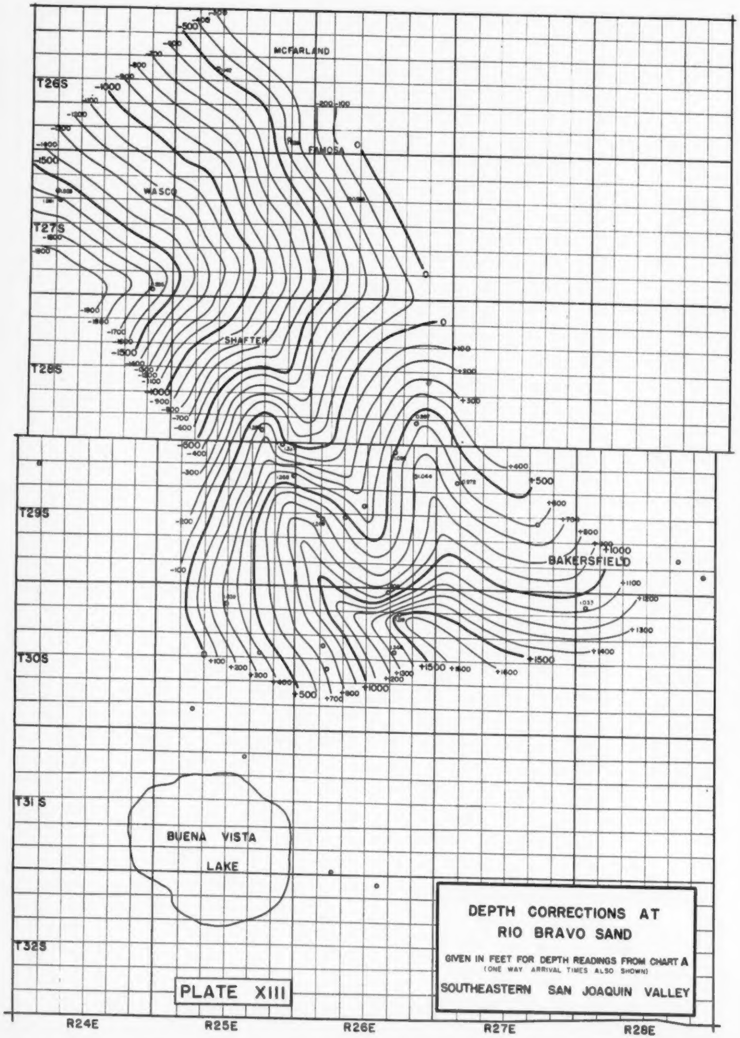
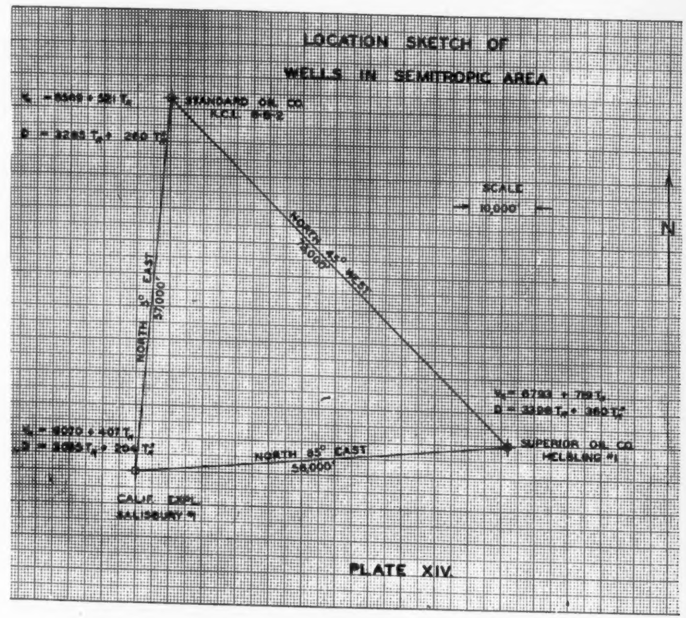


PLATE X
DEPTH CORRECTIONS AT
MARKER ABOVE STEVENS SAND
GIVEN IN FEET FOR DEPTH READINGS FROM CHART A
(ONE WAY ARRIVAL TIMES ALSO SHOWN)
SOUTHEASTERN SAN JOAQUIN VALLEY
MCFARLAND
FAMOSA
WASCO
SHAFTER
BAKERSFIELD
BUENA VISTA
LAKE
T26S
T27S
T28S
T29S
T30S
T31 S
T32S
R24E
R25E
R26E
R27E
R28E


MCFARLAND
FAMOSA
WASCO
SHAFTER
BAKERSFIELD
BUENA VISTA LAKE
T26S
T27S
T28S
T29S
T30S
T31 S
T32S
R24E
R25E
R26E
R27E
R28E
7000
7500
8000
8500
9000
9500
10000
10500
11000
11500
12000
12500
13000
13500
14000
PLATE XI
DEPTH OF RIO BRAVO SAND
(FEET)
FROM BASE OF WEATHERING TO TOP OF SAND
SOUTHEASTERN SAN JOAQUIN VALLEY


MCFARLAND
FAMOSA
WASCO
SHAFTER
BAKERSFIELD
BUENA VISTA LAKE
T26S
T27S
T28S
T29S
T30S
T31 S
T32S
R24E
R25E
R26E
R27E
R28E
7700
7800
7900
8000
8100
8200
8300
8400
8500
8600
8700
8800
8900
9000
9100
9200
9300
9400
9500
9600
9700
9800
9900
PLATE XII
AVERAGE VELOCITY TO
RIO BRAVO SAND
FROM BASE OF WEATHERING
(FEET PER SECOND)
SOUTHEASTERN SAN JOAQUIN VALLEY


DEPTH CORRECTIONS AT
RIO BRAVO SAND
GIVEN IN FEET FOR DEPTH READINGS FROM CHART A
(ONE WAY ARRIVAL TIMES ALSO SHOWN)
SOUTHEASTERN SAN JOAQUIN VALLEY
PLATE XIII
MCFARLAND
FAMOSA
WASCO
SHAFTER
BAKERSFIELD
BUENA VISTA
LAKE
T26S
T27S
T28S
T29S
T30S
T31 S
T32S
R24E
R25E
R26E
R27E
R28E


LOCATION SKETCH OF
WELLS IN SEMITROPIC AREA
STANDARD OIL CO.
SCALE
10,000'
N
NORTH 5° EAST
37,000'
SUPERIOR OIL CO.
HELBLING #1
NORTH 85° EAST
58,000'
CALIF. EXPL.
SALISBURY #1
PLATE XIV

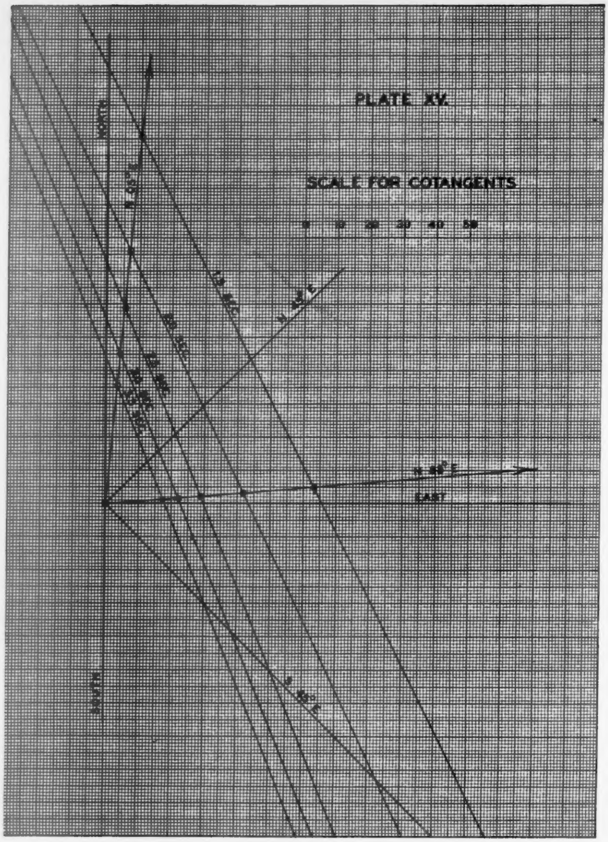


PLATE XV.
SCALE FOR COTANGENTS
0 10 20 30 40 50
NORTH
SOUTH
EAST

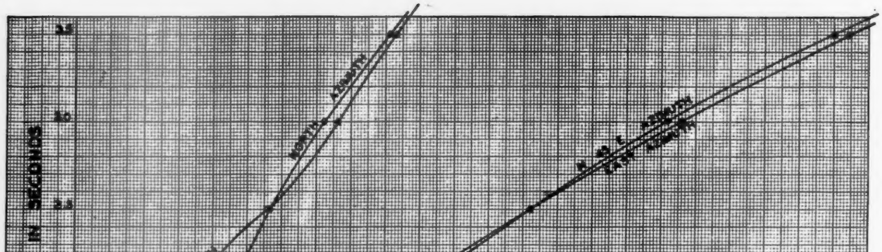


PLATE XVI.
SLOPE CORRECTIONS FOR AREA
BETWEEN
CALIF. EXPL. CO. SALISBURY #1
SUPERIOR OIL CO. HELBLING #1
STANDARD OIL CO. K.C.L. 8-B-2
VERTICAL REFLECTION TIME IN SECONDS
SLOPE CORRECTIONS - FEET PER 1000
NORTH AZIMUTH
EAST AZIMUTH

calculations. Take three wells in the Semitropic area: California Exploration Company's Salisbury No. 1; Superior Oil Company's Helbling No. 1; and Standard's K.C.L. 8 B-2. These are shown in Plate XIV. The velocity equations are:

$$(1)\ V_a = 6{,}070 + 407T_r$$
$$(2)\ V_a = 6{,}793 + 719T_r$$
$$(3)\ V_a = 6.569 + 521T_r$$

where V_a is the average velocity and T_r is the reflection time. These equations are changed to the depth form by multiplying by half the reflection time and we get:

$$(1)\ D_1 = 3{,}035T_r + 204T_r^2$$
$$(2)\ D_2 = 3{,}396T_r + 360T_r^2$$
$$(3)\ D_3 = 3{,}285T_r + 260T_r^2$$

Since the first well has the lowest velocity we will use this as a reference well in making the calculations. For any reflection time the difference in depth at the wells will be the difference between the equations. For (1) and (2)

$$D_2 - D_1 = 361T_r + 156T_r^2$$

If we divide this by the distance between the wells we get the tangent of the slope correction. The distance is 56,000 feet N. 85° E. The tangent of the dip correction then becomes:

$$\text{Tan correction} = .0064T_r + .0028T_r^2$$

This applies to the azimuth of the line from the California Exploration Company's Salisbury well to the Superior Oil Company's Helbling well. Similarly we can find that the tangent of the correction between the Salisbury well and the Standard well is:

$$\text{Tan correction} = .0044T_r + .001T_r^2$$

This applies to the azimuth of N. 5° E. We can solve the equations for various reflection times and tabulate them.

T_r	*For N. 85° E.*		*For N. 5° E.*	
	Cot	*Tan*	*Cot*	*Tan*
1.5	63.	.016	111.	.009
2.0	42.	.024	77.	.013
2.5	29.	.034	59.	.017
3.0	22.	.045	45.	.022
3.5	17.5	.057	36.	.028

To get corrections for any other given azimuth we may use the familiar cotangent method[7] (Pl. XV). The cotangents of the correction

[7] H. W. Kitson, "Graphic Solution of Strike and Dip from Two Angular Components," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 9 (September, 1929), pp. 1211–13.

for the two given azimuths are plotted from some point as the origin, to a convenient scale, in the direction of positive correction. The ends of the two lines are joined. The line connecting the ends is the strike of the plane of correction for that particular reflection time. The cotangent of the correction for any other azimuth is proportional to the length of the line from the origin to this strike line as measured along the azimuth. The cotangent measured off in this manner is converted into a tangent and multiplied by 1,000 to give the slope correction in feet per thousand (Pl. XVI). These corrections are calculated by assuming vertical reflections. There still remains a correction to be applied to the depths of the reflections, although it may be ignored if the velocity function is approximately correct and the slopes are used exclusively in working out the structure. Instead of using the velocity equations, the time-depth curves for the wells may be used instead. The writer believes that the equations are better for the purpose since they eliminate certain irregularities due to the lithologic alternations which should not properly be considered in getting the regional velocity gradient. The equations also permit a reasonable extrapolation of the data.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 25, NO. 7 (JULY, 1941), PP. 1363-1395, 15 FIGS.

GEOLOGY OF EOLA OIL FIELD, AVOYELLES PARISH, LOUISIANA[1]

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ABSTRACT

Eola, located in the Louisiana Gulf Coast area, in the south-central part of the state, was discovered by S. W. Richardson, in January, 1939. The location of the structure can be attributed solely to geophysics. Principal production is secured from sands at the top of the Sabine Wilcox of the lower Eocene at a depth of about 8,500 feet; commercial oil sands have been logged in some wells in the Cockfield and Sparta. To date, ninety oil wells have been completed from the Wilcox, and three from the Cockfield; twelve dry holes have been drilled on and adjacent to the field. Eola was the first field in the area to produce oil in commercial quantities from the Sabine Wilcox.

Structurally the field appears to be a large nose extending southeast from the Cheneyville salt dome, securing its north-west closure from a very complex system of normal faults. A total relief of about 400 feet on the top of the Wilcox has been established by the drill, with a maximum elevation of 300 feet of the producing sand above its water level.

The field has produced 4,561,544 barrels of oil to December 1, 1940, from about 1,750 acres. The probable ultimate recovery is more than 60 million barrels, indicating Eola to be one of the major petroleum reserves in the area.

ACKNOWLEDGMENTS

For permission to publish this analysis of data secured from their wells, the writer is indebted to S. W. Richardson, the Amerada Petroleum Corporation, and other operators at Eola. To the personnel of these companies, thanks are due for invaluable suggestion and criticism, and for helpful coöperation through the entire development of the field. Acknowledgment is due L. W. MacNaughton, consulting geologist of Dallas, Texas, and A. M. Lloyd, geologist for Sun Oil Company in Shreveport, Louisiana, for their aid to the writer in the early stages of study and interpretation of this material. Jay B. Wharton, Jr., assisted greatly in preparation of well reports and figures accompanying this paper, and constructed the relief model of which a photograph is included.

INTRODUCTION

Eola is located in the extreme southwest corner of Avoyelles Parish about 2 miles south of the town of Bunkie. Physiographically it lies on the fertile and relatively flat flood-plain of the Red River. It is bisected by the deeply entrenched meanders of Bayou Boeuf, exposing recent sediments only. It is interesting to note that the bayou at this point follows one of the ancient courses of the immense prehistoric Red-Atchafalaya River system,[3] whose high bordering terraces pass about three miles west of the field.

[1] Read before the Association at Chicago, April 12, 1940. Manuscript received, January 6, 1940.

[2] Consulting geologist and paleontologist.

[3] H. V. Howe and C. K. Moresi, "Geology of Lafayette and St. Martin Parishes," *Lousiana State Geol. Survey Bull. 3* (1933), p. 37.

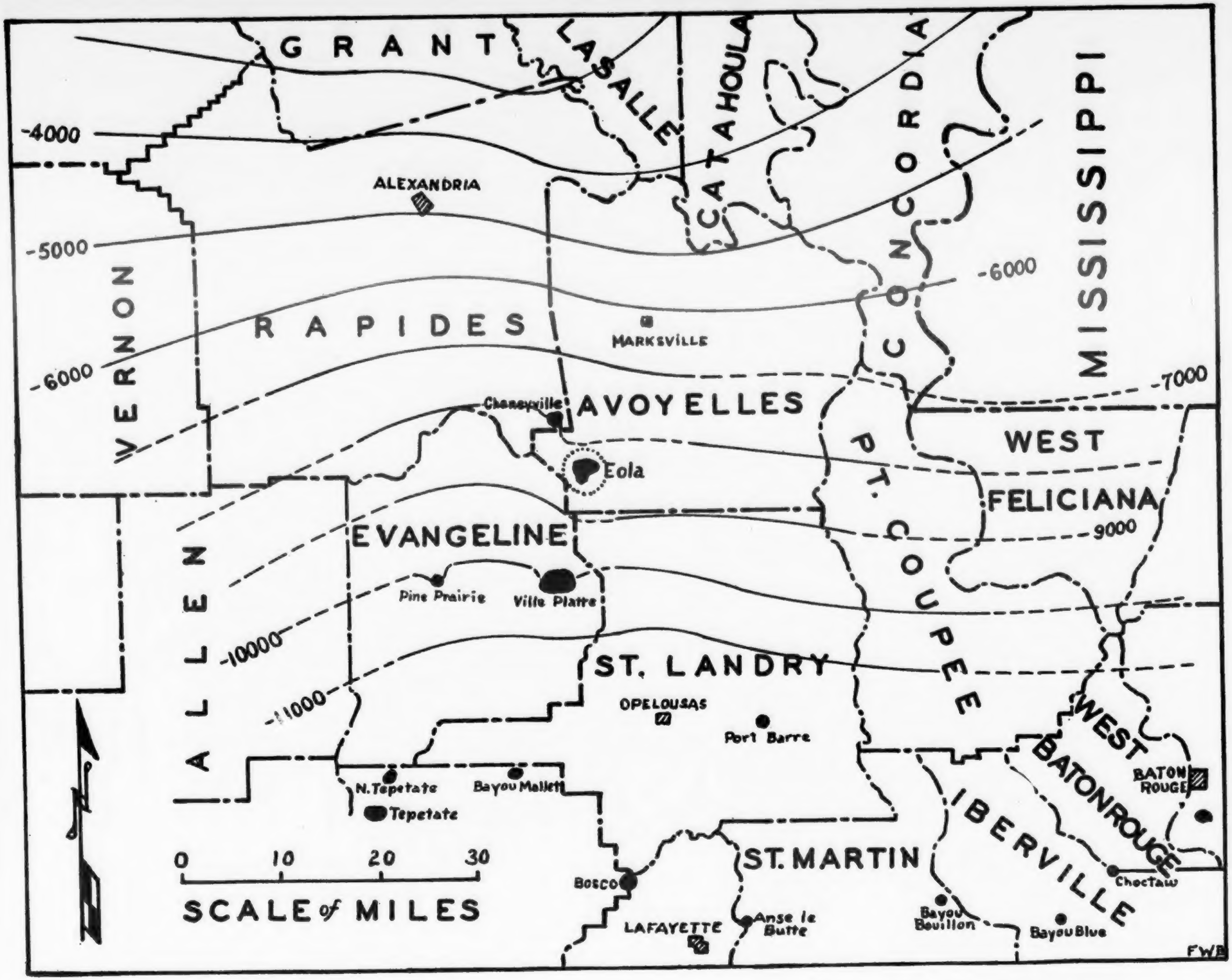


FIG. 1.—Sketch map of south-central Louisiana showing relation of Eola to adjacent fields, and to regional sub-sea Wilcox structure.

The land is largely in cultivation in cotton and sugar cane. Surface elevation varies from 48 to 70 feet above sea-level. It is readily accessible by highway and railroad. No indication of structure can be noted on the surface.

The field is of particular interest to the oil industry because it marked the first production in coastal Louisiana from the Sabine Wilcox sands of the lower Eocene. Lying in the zone of the so-called Conroe trend the structure was noted many years before its development, but long neglected after Cockfield production in the area proved so disappointing. The development of Wilcox production here provided the touchstone along the Sparta-Wilcox trend for one of the most active leasing, geophysical, and wildcat campaigns the state has known.

Detailed paleontological determinations and careful systematic coring, together with electrical logs on each well, give a mass of data unexcelled for exact study of stratigraphic and structural history. Geologically, this field is particularly interesting. It presents a structure radically different from others in this area, in that the formation of the producing closure appears to be principally a result of faulting rather than folding, as is developed in the following figures and discussion.

HISTORY OF DEVELOPMENT

Eola has a long history of geophysical and leasing activity prior to its actual development as a producing field. Many agencies have laid claim to its discovery. Apparently one of the earliest was by the Wilcox Oil and Gas Company with torsion balance in 1928. A block of leases was formed by this company but no drilling undertaken. Leases were successively held over the structure by many concerns, both major companies and independents. The present development was inaugurated by the rediscovery of the structure, together with the Cheneyville dome, by the Adams Louisiana Company (now Adams Oil and Gas Company) in a reconnaissance survey in 1933. This company outlined the field with reflection seismograph and interested the Amerada Petroleum Corporation in the area. Geophysical exploration was continued by the two companies jointly and, in 1934, a block of approximately 3,000 acres was taken.

Until late in 1938 much other geophysical work was done in this area, all reporting indications of structure, but further development being blocked by the lack of sufficient available leases. The field was again detailed with reflection seismograph by S. W. Richardson and all available leases taken.

FIG. 1.—Sketch map of south-central Louisiana showing relation of Eola to adjacent fields, and to regional sub-sea Wilcox structure.

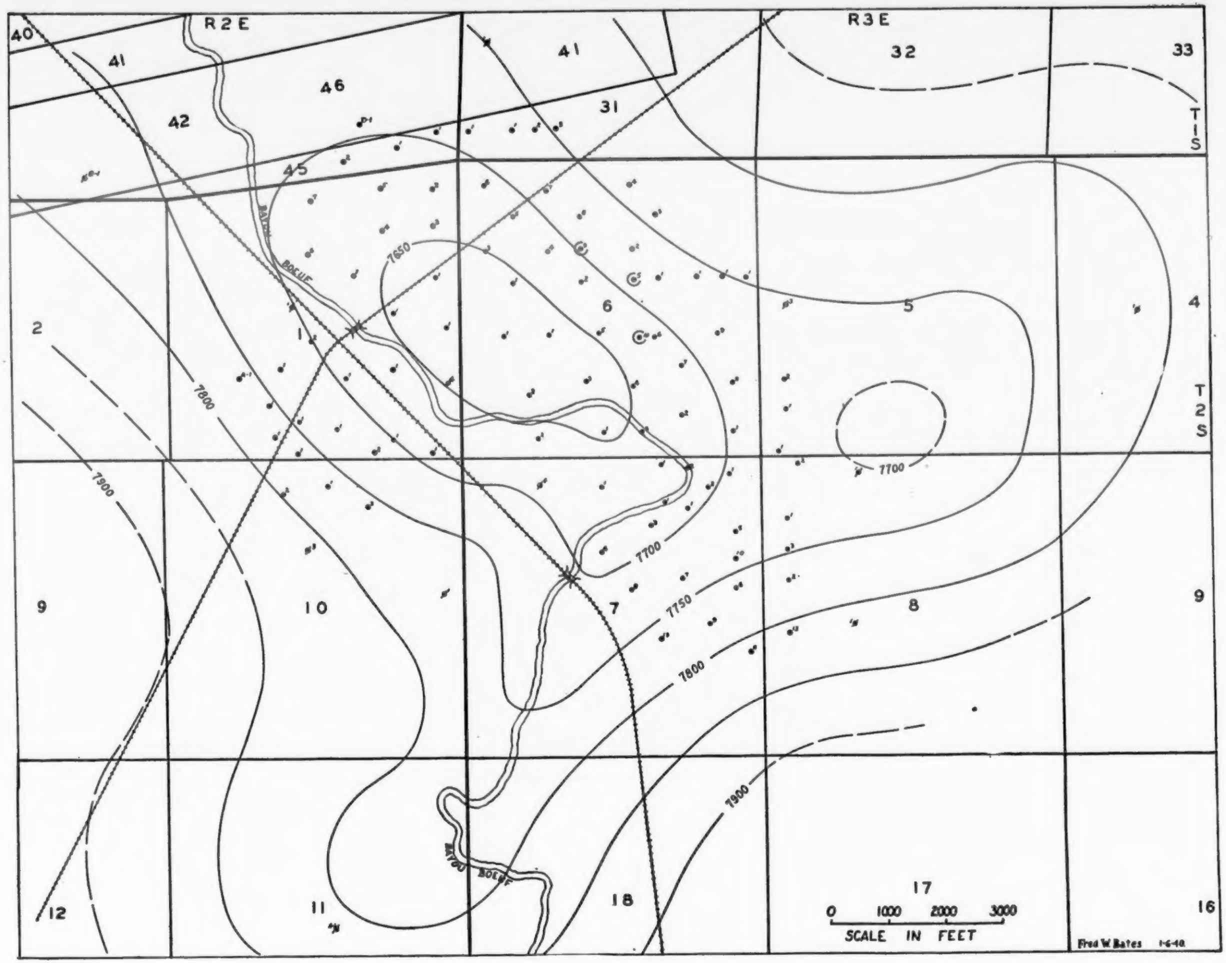


FIG. 2.—Reflection-seismograph structure map of Eola field.

This last seismograph picture (Fig. 2) shows about 100 feet of closure centering in Sections 1 and 6, open at the northwest toward Cheneyville, with well defined noses extending east into Section 5 and southwest into Section 11. It is interesting to bear these features in mind as they are a strikingly accurate prognostication of the structure, as shown by subsequent development.

The discovery well, Haas Investment Company No. 1, was completed by S. W. Richardson and associates in January, 1939, as an excellent producer from Wilcox sands encountered at 8,440 feet. Following its discovery Eola had a very rapid but orderly development, resulting in a total of ninety commercial Wilcox producers, three from the Cockfield, and twelve dry holes, as shown in Figure 3, until to-day the field is almost completely drilled. The producing area embraces between 1,700 and 1,800 acres, of which the bulk is held by the Amerada Petroleum Corporation and S. W. Richardson, with smaller parts leased by the Gulf, Sun, Magnolia, and several independent operators.

Of the dry holes, those drilled by J. Edward Jones in Section 4, and the Gulf States in Section 8, attempted to establish production on the east nose. Wells abandoned by Richardson in Section 11 and two by the Amerada in Section 10 were attempts to prove the southwest nose. Jones' Haas No. 1 in Section 8, the Amerada's Stokes No. 1 in Section 41, the Gulf's M. S. Mouliere No. 1 in Section 1, and Richardson's Haas No. 1-B in Section 42 were edge extensions structurally too low to produce. The Amerada's Whitlow No. 4 in Section 1 and Irion No. 4 in Section 7 were dry by virtue of their position on a downdropped fault block.

STRATIGRAPHY

Wells at Eola encounter a well defined and typical section of Gulf Coast Tertiary sediments. The accompanying columnar section (Fig. 4) shows the general lithologic character of each formation together with the diagnostic faunal zones noted in each. Foraminiferal correlations at Eola were particularly accurate and useful during development because of the large number of readily distinguishable microfaunal zones of short vertical range. Fortunately each producing sand is marked by superjacent faunal zones making accurate coring possible. Most of the paleontologic changes are correlated with lithologic breaks readily discernable on the electrical logs, giving a close check on field technique and future application of determinations.

Close correlation from electrical logs above the top of the Vicksburg at about 5,700 feet is not possible, due to the lack of diagnostic electrical characteristics, and the rapid lateral variation in facies. For

FIG. 2.—Reflection-seismograph structure map of Eola field.

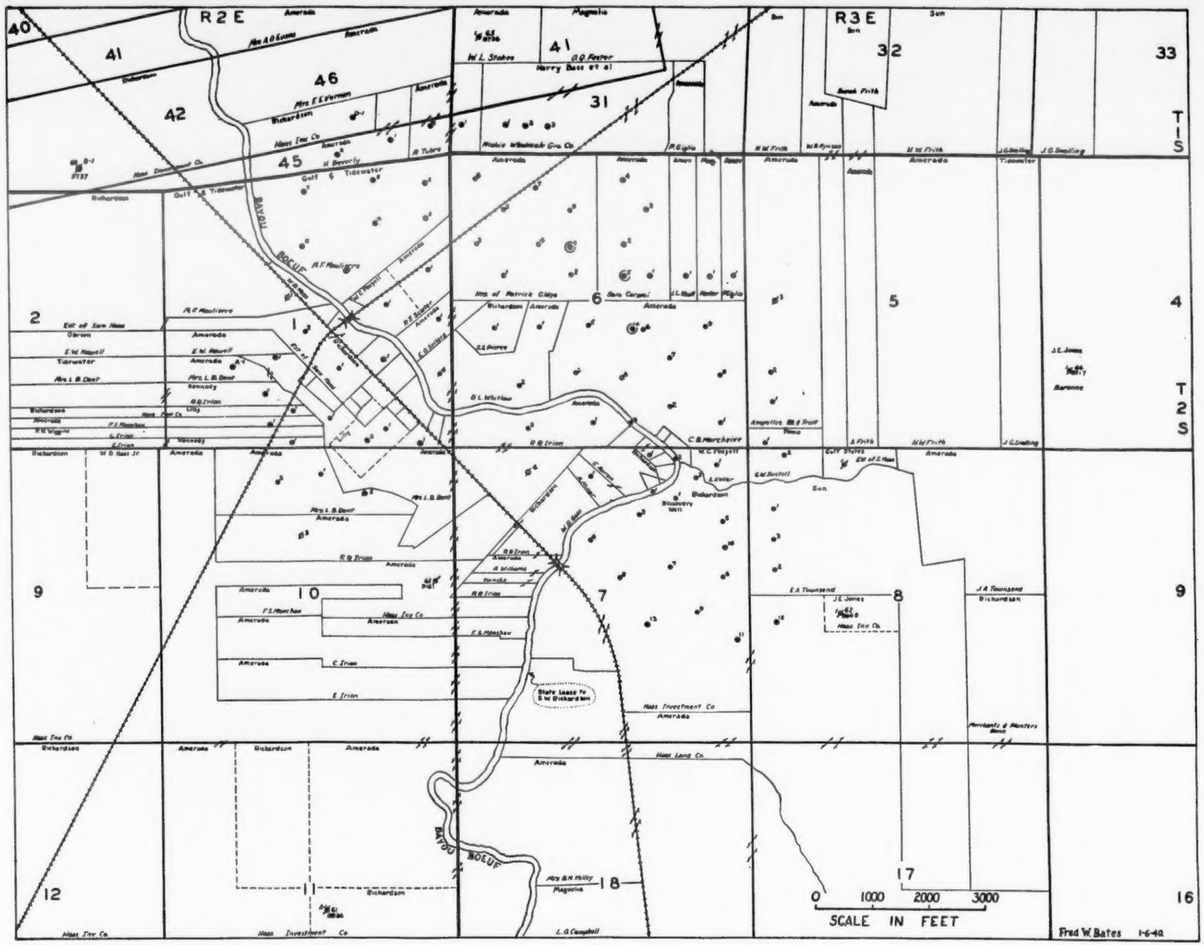


FIG. 3.—Development map of Eola field. All wells are drilled to Wilcox except three Cockfield producers (shown by double circle).

FIG. 3.—Development map of Eola field. All wells are drilled to Wilcox except three Cockfield producers (shown by double circle).

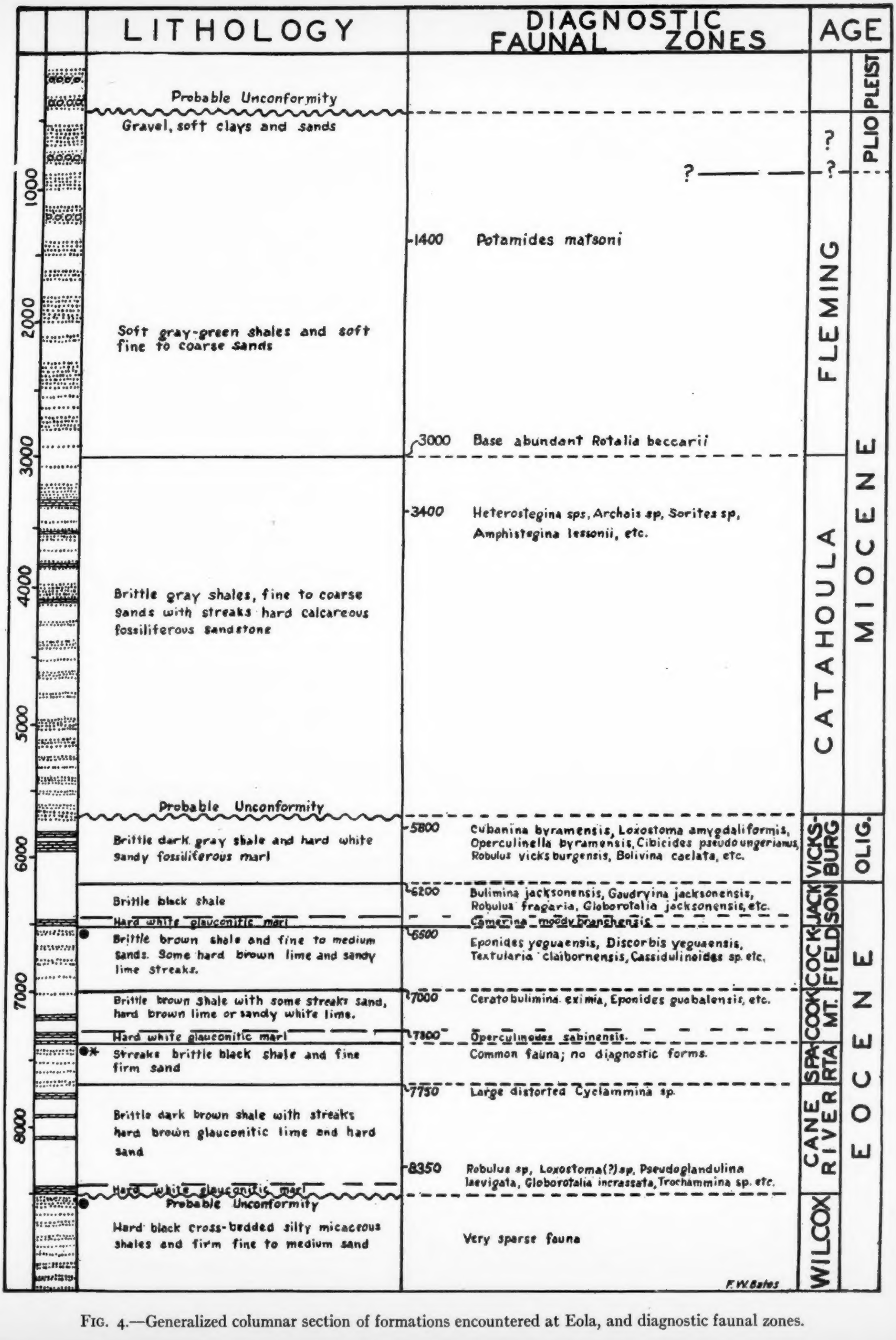


FIG. 4.—Generalized columnar section of formations encountered at Eola, and diagnostic faunal zones.

this reason the cross section of electrical logs (Fig. 5) reproduces the surveys from 3,000 feet down only. This cross section illustrates the high degree of lateral persistency of the electrical characteristics of formations below the Vicksburg, which has made possible close, accurate correlation and graphic analysis of faulting, and structural, and stratigraphic change.

For convenience the formations are discussed in descending order as encountered by the drill, rather than in the order of their deposition.

Post-Oligocene sediments.—The Pleistocene consists here of soft red and green clays, fine to coarse chert gravel, and fine to coarse subround sand containing fresh water. Its base, a possible unconformity, has been established by the Louisiana Geological Survey[4] at about 300 feet from evidence secured in shallow water wells near by. No evidence is offered either for or against the presence of Pliocene sediments, though a zone of possible Pliocene lithologically similar to Pleistocene is shown in the chart.

The upper part of the Miocene resembles the Plio-Pleistocene sediments to a depth of about 1,500 feet and similarly contains fresh or brackish water. Below this depth little gravel is encountered, the clay grades into a soft to brittle gray-green shale and the sands contain salt water. In the field, the zone of gravel and fresh water is shut off by surface casing. The Catahoula, found between 3,000 and 5,700 feet contains some streaks of fossiliferous sandy white limestone and calcareous sandstone.

The youngest paleontological marker is *Rangia johnsoni*, a small pelecypod, occurring, with some associated macrofossils, at about 800 feet and tentatively considered to be the top of the Miocene and the top of the Fleming. Another shell zone at about 1,400 feet is characterized by the appearance of *Potamides matsoni*. An obscure faunal change marked by a decrease in *Rotalia becarii*, abundant in the upper Fleming, is considered by the Louisiana State Geological Survey[5] to mark the top of the Catahoula.

The first reliable paleontological marker is the *Heterostegina* zone, with abundant microfossils, found just below the top of the Catahoula at about 3,400 feet, and including the following forms: *Heterostegina texana*, *Miogypsina* sp., *Archais* sp., *Sorites* sp., *Quinqueloculina crassa*, *Siphonina advena*, *Robulus americanus*, *R.* spp., *Textularia mississippiensis*, *Uvigerina* spp., *Globigerina bulloides*, *G. inflata*, *Discorbis*

[4] H. N. Fisk, personal communication, March, 1940.

[5] H. N. Fisk, personal communication, March, 1940.

candeiana, *Cythereis* spp., *Cytheridea* spp., *Amphistegina lessonii*, *Eponides antillarum*, *et cetera*. No *Discorbis* or *Marginulina* zones have been noted at Eola.

None of these Miocene markers was determined regularly since structure is not strongly reflected at these shallow depths, and correlation is usually obscure. It will be noted that the Catahoula and its included *Heterostegina* zone is here referred to the Miocene, following the practice of the United States Geological Survey and the Louisiana Geological Survey.[6]

Oligocene Vicksburg.—This formation consists of hard white glauconitic fossiliferous marl with streaks of firm dark gray brittle shale grading, in the lower half of its total thickness of 400 feet. into a pure black shale. This is one of the most easily distinguished formations in the column, both on electrical logs and in cuttings, marked by a sharp change from the thick broken sparsely fossiliferous sands of the basal Miocene into a section of abundantly fossiliferous shale and limestone. The Vicksburg contains a typical fauna including the following Foraminifera:—*Operculinella byramensis*, *Cibicides concentricus*, *C. pseudoungerianus*, *C. cookei*, *Textularia mississippiensis*, *Bulimina sculptilis*, *Bolivina caelata*, *Loxostoma amygdalaeformis*, *Cubanina* (*Liebusella*) *byramensis*, *Quinqueloculina byramensis*, *Robulus americanus*, *R. vicksburgensis*, *Globulina inaequalis*, *Palmula vicksburgensis*, *Uvigerina vicksburgensis*, *Siphonina advena*, *et cetera*.

No subdivision of the formation has been possible paleontologically; some local correlation is possible from characteristics of the broken limestone streaks on the electrical resistivity curves. A short section of solid shale of questionable age is present between the basal sands of the Miocene and the first definite Vicksburg fauna. This zone may be of Chickasawhay age, although no paleontological evidence has been noted. It has been tentatively assigned to the Oligocene in the writer's reports on the basis of lithology although the top of the true Vicksburg is selected at the top of the limestone section.

Strong evidence of a major unconformity above the Vicksburg is offered by the rapid variation in the field as well as in the surrounding area of thickness of the "Oligocene" shale zone previously discussed. Correlation with wells downdip shows this shale member thickening from about 60 feet at Eola to more than 100 feet within 10 miles, while updip the interval shortens until the limestone is first in contact with the basal Miocene sands, and finally, in wells close to Marksville,

[6] H. V. Howe, "Review of the Tertiary Stratigraphy of Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 6 (June, 1933), reprinted in *Gulf Coast Oil Fields* (Amer. Assoc. Petrol. Geol., 1936), pp. 405–17.

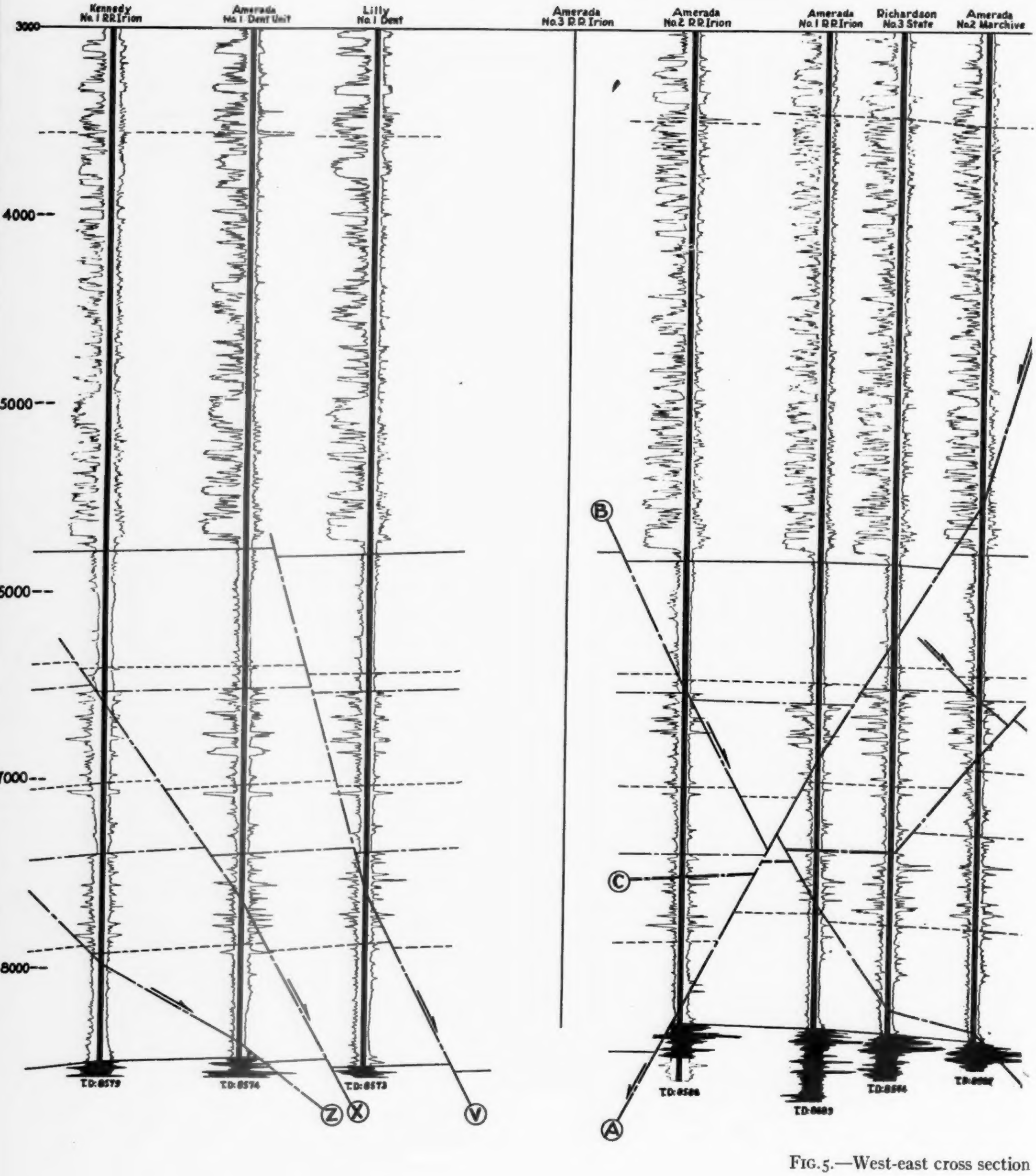
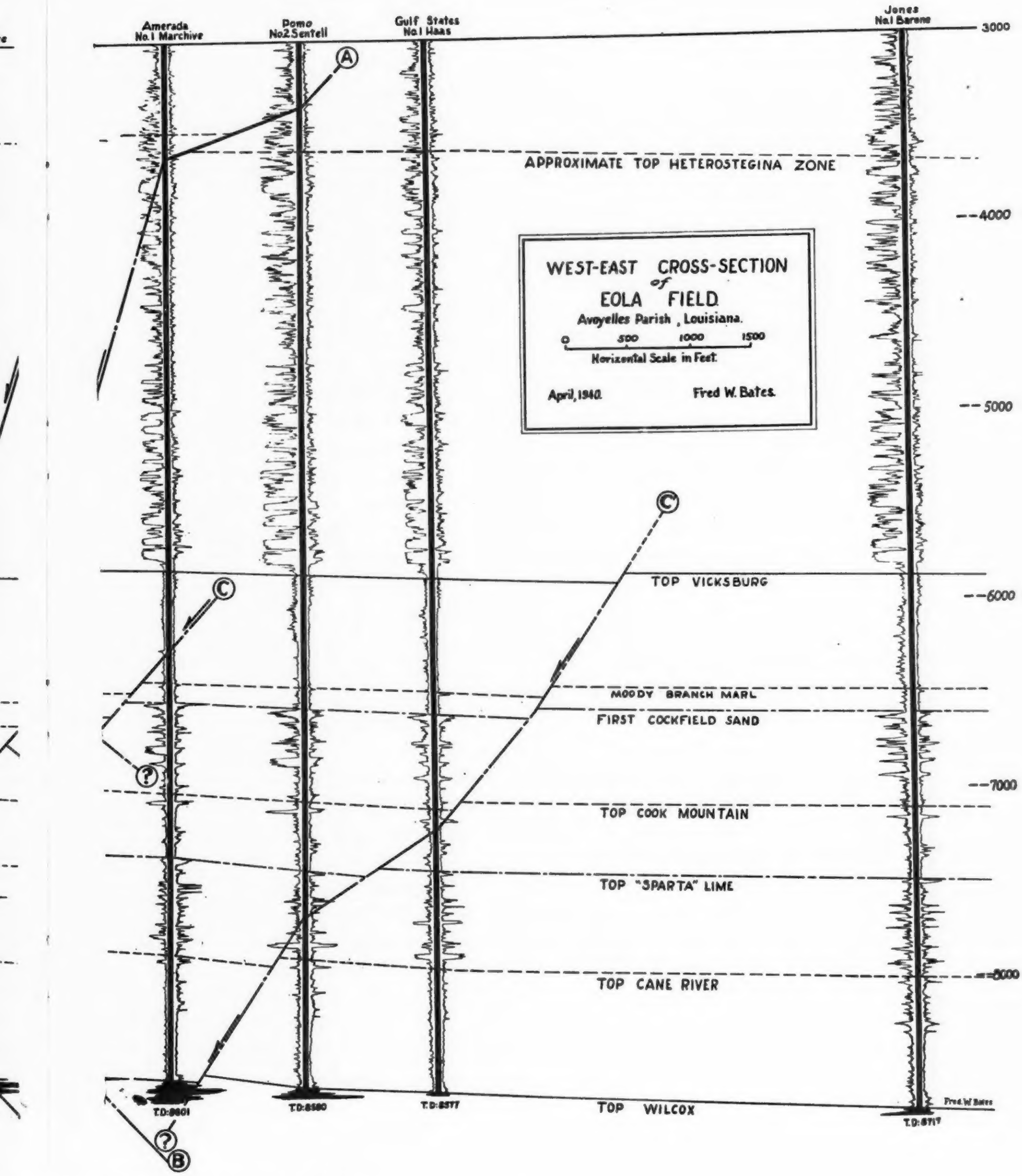


FIG. 5.—West-east cross section of



tion of Eola drawn from electrical logs.

the entire upper half of the limestone has apparently been lost in the unconformity. This feature may be a result of regional changes in sedimentation, but this appears improbable as the thickness of the Vicksburg shale below the limestone remains approximately constant.

Eocene Jackson.—Lithology of the 300-foot thick, prominently marine Jackson is identical with the base of the overlying Vicksburg, being a firm brittle black shale. The upper Jackson fauna shows a gradual transition from the Vicksburg fauna, notable being the change of *Bulimina sculptilis* of the Vicksburg into *Bulimina jacksonensis*. The transition zone at the base of the Vicksburg has been referred to the Red Bluff formation of Mississippi by some paleontologists. Foraminifera diagnostic of the top of the Eola Jackson are *Bulimina jacksonensis*, *Siphonina jacksonensis*, *Gaudryina jacksonensis*, *Robulus fragaria*, *R. alato-limbatus*, *Uvigerina topilensis*, and *Eponides jacksonensis*, which are found together with many microfossils also present in the Vicksburg. Fifty to one hundred feet below the top of the formation the forms *Textularia hockleyensis*, *Hantkenina alabamensis*, and *Globorotalia jacksonensis* are added. The formation becomes increasingly glauconitic in the lower third of its thickness. An excellent marker is provided by the Moody Branch marl member, a firm white glauconitic fossiliferous marl about 20 feet thick lying approximately 60 feet from the base of the formation. This marl, together with the Jackson shales below it, contains a strong Jackson fauna with the addition of *Camerina moodybranchensis*, *Operculina vaughani*, *Textularia dibollensis*, and a large smooth many-chambered species of *Robulus* with strongly limbate sutures.

Claiborne group.—The Louisiana Claiborne series of the Eocene has been redivided by Howe[7] into four formations: Cockfield, Cook Mountain, Sparta, and Cane River. The lithology of the entire group is similar, consisting of brittle dark brown slightly lignitic shales, fine to medium firm laminated, slightly micaceous, lignitic or glauconitic sands, and some hard white or brown glauconitic marls. The proportions of these components vary for each formation, however, and each possesses some distinguishing lithologic and paleontologic criteria.

Cockfield.—The Cockfield is a predominantly sandy combination of the different Claiborne facies about 500 feet in thickness. The nearshore or lagunal deposition of its upper part is attested by the crossbedding exhibited in many of the thinly laminated sands, by the abundant carbonaceous material, and by the relatively rare shallow-marine to littoral faunal characteristics. The fauna includes a rather sparse Claiborne association: *Discorbis yeguaensis*, *Cassidulinoides*

[7] H. V. Howe, *op. cit.*, pp. 391–402.

sp., *Eponides yeguaensis*, *Textularia claibornensis*, *Siphonina claibornensis*, *Globigerina inflata*, *Uvigerina* spp., *Robulus rotulata*, *R. jugosus*, *et cetera*. The form *Nonionella cockfieldensis*, diagnostic of the top-most portion of the formation both at the outcrop and in the subsurface of surrounding areas, has been noted at Eola also, but since it is rare and ranges upward into the Moody Branch marl member of the Jackson, it has not been used as a marker here.

The lower part of the Cockfield becomes more marine, being predominantly shale with a few brown glauconitic limestone members and a more abundant fauna.

Cook Mountain.—A purely marine formation a little more than 400 feet thick, transitional both lithologically and paleontologically from the overlying shales of Cockfield age. The abundant fauna is characterized by *Ceratobulimina exemia*, *Eponides guayabalensis* (or *mexicanus*), *Dentalina mexicana*, *Textularia mexicana*, *Robulus mexicanus*, *et cetera*. A hard white finely glauconitic microcrystalline limestone about 100 feet thick is found 200 feet below the top.

The bottom 100 feet consists of a broken hard white coarsely crystalline fossiliferous marl containing numerous large glauconite grains and sections of the abundant large diagnostic *Operculinoides sabinensis*. This member provides so valuable a marker for the base of the Cook Mountain and top Sparta (with which formation it bears an intercalated relationship) that the writer, in reports on wells in the Eola field, has designated it as "Sparta" limestone. Its top can be readily determined lithologically in cuttings, from paleontological analysis, drilling action, or electrical logs.

Sparta.—These sediments indicate a retreating Claiborne sea since they show shallow-marine and lagunal characteristics similar to the Cockfield. Fine firm cross-bedded laminated micaceous sands and hard brittle dark brown to black carbonaceous shales, with a few streaks of fossiliferous white marl near the top, make up the 400 feet of Sparta section. Sands in the top are thin, few more than 10 or 15 feet thick; sands toward the base are more massive, slightly coarser and more glauconitic, many showing local cross-bedding and including large, worn pelecypod shells such as might be found in a reworked beach or dune deposit.

At Eola this formation is strikingly similar to Spooner's[8] description of the outcrop Sparta, both in thickness and composition, allowing only for its compaction resulting from burial.

The fauna is again fairly rare, a typical Claiborne assemblage with

[8] W. C. Spooner, "Interior Salt Domes of Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 3 (March, 1926), p. 236.

the addition of several new forms including ***Robulus nudicostatus*** (or *vacavillensis*), *Siphoninella claibornensis* and *Asterigerina* sp. The lack of paleontological criteria for determination of the top of this formation makes the overlying so-called "Sparta" (basal Cook Mountain) marl a particularly valuable marker as previously mentioned.

Cane River.—A deepening Claiborne sea deposited a marine series of dark brown shales with some streaks of glauconitic marl, brown near the top of the 600-foot section, white in the basal 50 feet. The Eola section again corresponds closely with Spooner's[9] type description. Subdivision at the outcrop of the Cane River by Shearer[10] into a shale member above and a basal marl member are also applicable here. His description, allowing for the metamorphic changes of compaction, is suitable for Eola.

> The top of the upper member is sandy shale, which grades downward into smooth, plastic, slightly calcareous clay-shale. This material is characterized by its dark chocolate-brown color, generally specked and streaked with light green. It is all marine and Foraminifera are plentiful.
>
> The lower member consists of fossiliferous, sandy, highly glauconitic marl or soft limestone. It is commonly logged as "salt and pepper sand" because of the appearance of the white limestone with grains of dark glauconite.

These subdivisions are correlative, at least in part, with the Reklaw above and Carrizo below, of other areas.

The top of the upper member of the Cane River shows a large and abundant Claiborne faunal assemblage with the addition of a large diagnostic characteristically distorted *Cyclammina* sp. The fauna becomes rare in the lower part of the shale member, with an abrupt increase at the base bringing in a new association including: *Globigerina mexicana*, *G. inflata*, *Globigerinoides* sp., *Globorotalia crassata*, *Glandulina* cf. *laevigata*, *Bifarina* (*Loxostoma?*) sp., *Eponides guayabalensis* (or *mexicanus*) var., *Trochammina* sp., *Robulus rotulata*, *R. jugosus*, and a *small diagnostic Robulus* showing sharply raised sutures and keel, and an embossed umbilical area with a depressed center. This latter association has proved particularly valuable at Eola and elsewhere on the "Wilcox trend" as a marker for coring the Wilcox.

There is considerable evidence of an unconformity separating the basal Cane River marl from the Wilcox, as discussed later.

Sabine Wilcox.—The use of the term "Wilcox" as a formation name is inaccurate and undesirable, as discussed by Howe.[11] Its prev-

[9] W. C. Spooner, *op. cit.*, pp. 235–36.

[10] H. K. Shearer, "Geology of Catahoula Parish, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 4 (April, 1930), p. 441.

[11] H. V. Howe, *op. cit.*, pp. 386–391.

alence in the literature and in popular expression is the writer's excuse for continuing its use here. Culbertson[12] and others have recommended application of the term "Sabine" to the formation, retaining "Wilcox" as a subgroup name applied to the upper shallow-marine facies. Since few wells at Eola penetrated more than a few hundred feet of Wilcox sediments, and none reached below the upper facies, the use here of "Wilcox" should be justified.

These sediments at Eola are composed of alternating beds of hard black silty lignitic micaceous shale, hard white cross-bedded siltstone laminae, and firm fine to medium micaceous or glauconitic sands. Their shallow-marine or lagunal origin is evident, while certain of the coarser-grained sands contain large pelecypod (*Venus* sp.) fragments, clam borings, *et cetera*, which together with their discontinuity suggest beach or bar deposits, either in place or reworked. The deepest penetration of the Wilcox at Eola, 1,200 feet in Richardson's Haas Investment Company No. B-1, shows no change in the type of sedimentation.

The lack of continuity of the individual beds is well known. Even across the field (Fig. 6) there is considerable change in the nature and thickness of the sand bodies. No correlation of the Wilcox section with wells in adjacent areas is possible. About 200 feet below the top a thin zone of hard dark sandy glauconitic fossiliferous marl containing numerous specimens of *Discocyclina* sp. may be correlative, though it has been described in too few wells here to be useful. The microfauna is a very rare brackish-water association consisting of small arenaceous forms, with some *Globigerina* spp., *Robulus* spp., and Ostracoda. Determination of the top of the formation has been made purely on the basis of lithologic change from the brown shales and white glauconitic marl of the Cane River, to the black micaceous shale and fine cross-bedded sands of the Wilcox. Electrical logs display a characteristic increase in resistivity at the top Wilcox, as shown in Figures 5 and 6.

There is some evidence that the top of the Wilcox as described here corresponds stratigraphically with the basal Cane River or Carrizo, as discussed by Culbertson.[13] Considerable study and field research on this problem has been conducted by the Louisiana Department of Conservation[14] and forthcoming publications will present this evidence.

[12] J. A. Culbertson, "Downdip Wilcox (Eocene) of Coastal Louisiana and Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 11 (November, 1940), pp. 1892–94.

[13] J. A. Culbertson, *op. cit.*, pp. 1915–18.

[14] J. Rukas, personal communication, March, 1940.

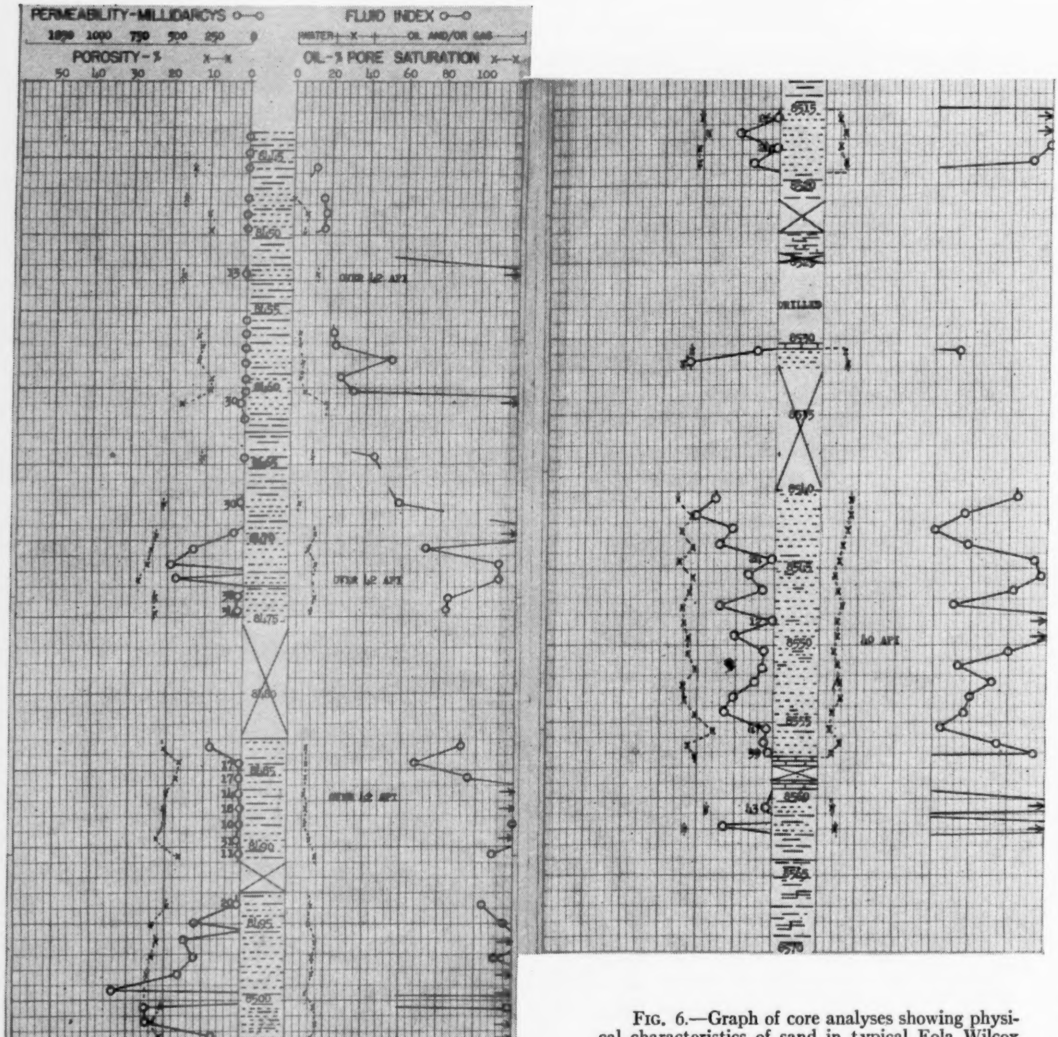


FIG. 6.—Graph of core analyses showing physical characteristics of sand in typical Eola Wilcox producer. S. W. Richardson's Haas Investment Co. No. 2; elevation, 65.8 feet.

PRODUCING SANDS

Sand bodies at the tops of the Cockfield, Sparta, and Wilcox formations contain oil at Eola wherever present in sufficient effective thickness above the water level.

Cockfield.—Twenty to thirty feet of soft broken medium-grained slightly glauconitic, lignitic, or micaceous sand. Water level varies between $-6,390$ and $-6,440$ in the different fault blocks. Where it contains oil, the sand shows high permeabilities and saturations up to 9 per cent by volume in dark brown oil of 36° gravity. Only a very small part, about 240 acres, of the structure will produce from this formation. Three wells, indicated by a double circle on the maps, are completed in this sand. It is doubtful if any additional wells will be drilled exclusively for Cockfield production, as this oil can be recovered more economically through wells already drilled after depletion of the deeper reservoirs. No gas cap is found in the Cockfield.

Sparta.—Several bodies of fine firm slightly lignitic and micaceous sand between 10 and 20 feet in aggregate thickness are found at the top of the Sparta. Wherever present above the water level at about $-7,435$ to $-7,460$, these sands will probably produce gas distillate. Cores show low permeabilities and saturations between 0.8 per cent and 2.0 per cent by volume in greenish brown high-gravity oil or distillate. No wells produce at Eola from Sparta sands at present; this oil will probably be recovered solely by plugging back existing wells after depletion of the Wilcox. The producing area is estimated at about 1,400 acres. That these sands offer a considerable reserve is indicated by production from the physically similar Haas sand of the Sparta in the near-by Ville Platte field, Evangeline Parish, Louisiana.

Wilcox.—All production from this formation to date has been secured from the top hundred feet. It is a firm fine to medium slightly micaceous or glauconitic sand with cross-bedded streaks of hard black micaceous shale. Analyses (Fig. 6) show an average porosity of about 22 per cent, permeabilities from zero to 900 millidarcys and oil saturations from 1.0 per cent to 3.8 per cent by volume in dark green 42° gravity oil. Wherever present, with sufficient permeability, above the water level established at $-8,520$ feet these sands are uniformly well saturated. The area underlain by Wilcox production is about 1,750 acres. There is no free gas cap except in wells high on the west side of the major fault "Z" on the southwest flank. Complete isolation of this fault block is proved by the presence elsewhere in the field of Wilcox sands 200 feet higher which show no gas.

Recent development, in LaSalle Parish, of excellent commercial production from sands deeper stratigraphically in the Wilcox, indi-

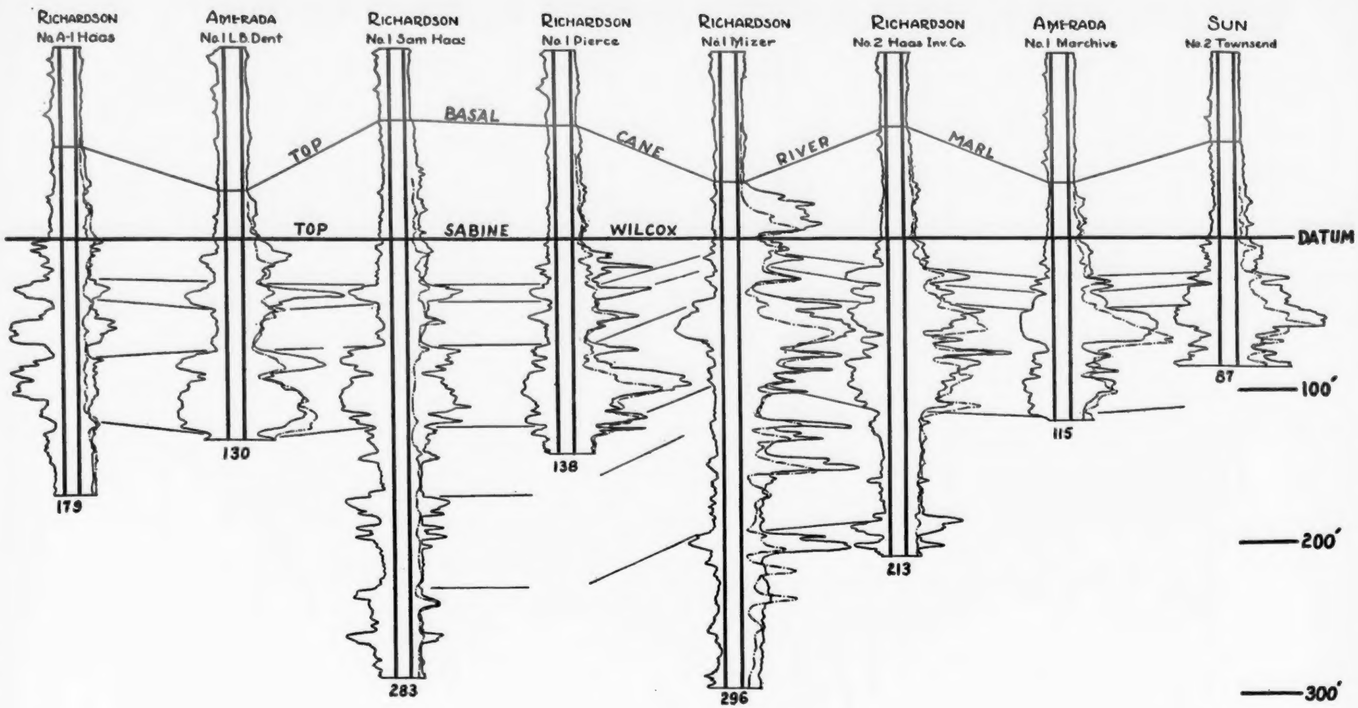


FIG. 7.—Approximate cross section of Eola showing discontinuity of producing sands from detailed electrical logs. Drawn with top Wilcox as datum and depth of penetration shown for each well. No horizontal scale.

cates the possibility of discovering such deep production at Eola also. Several off-structure dry wells drilled more than 1,000 feet into the formation have established the presence of thick permeable sand bodies below those now producing. No deep wells have been drilled sufficiently high on structure to prove or disprove the possibility of deeper production here.

Figure 7 shows the rapid lateral variation in development and thickness of the producing sand across the field. The hundred-foot-thick sand zone noted in wells on the east part of the cross section (as in most of the field) shales up to the west in its upper middle part, until wells on the west side show two distinct sand members, a 10-foot upper sand being separated from the lower main body by a 30-foot shale break. The well on the extreme left of the cross section, Richardson's Haas Investment Company No. A-1, is located more than a mile south of production and shows redevelopment of a sand in this shale interval. Some structural thinning is noted in the Wilcox in wells high on structure. The shortening in the cross section of intervals in Richardson's Mizer No. 1 is probably, in part, a result of faulting encountered in this well near the top of the Wilcox.

The unconformity previously mentioned at the Cane River-Wilcox contact is shown in Figure 7 by the variation in thickness of the basal Cane River marl, and of the Wilcox shale above the first sand. Part of this effect is probably also caused by variations in the Cane River sedimentation; part is an effect of minor faulting which seems to concentrate at the base of the Cane River. However, most cores of the contact show an irregular erosional Wilcox surface, overlain by a contact zone of from a few inches to several feet of coarse slightly indurated granular glauconite with irregular streaks and reworked fragments of Wilcox shale.

STRUCTURE

Eola is a very deep dome, roughly oval, located like several near-by oil fields on a broad gentle regional nose extending in a general southerly direction from the Tullos-Urania uplift in Grant and La-Salle parishes. The Wilcox producing structure is about 2½ miles long, by 1½ miles wide, with its major axis extending northwest toward the Cheneyville salt dome with which it bears a very close relationship. The uplift centers at the middle of the common line between Secs. 6 and 7, T. 2 S., R. 3 E. A maximum relief of about 400 feet has been established by the drill, though the total uplift of the structure is probably considerably greater. The top of the Wilcox sand shows a maximum elevation of three hundred feet above its water level.

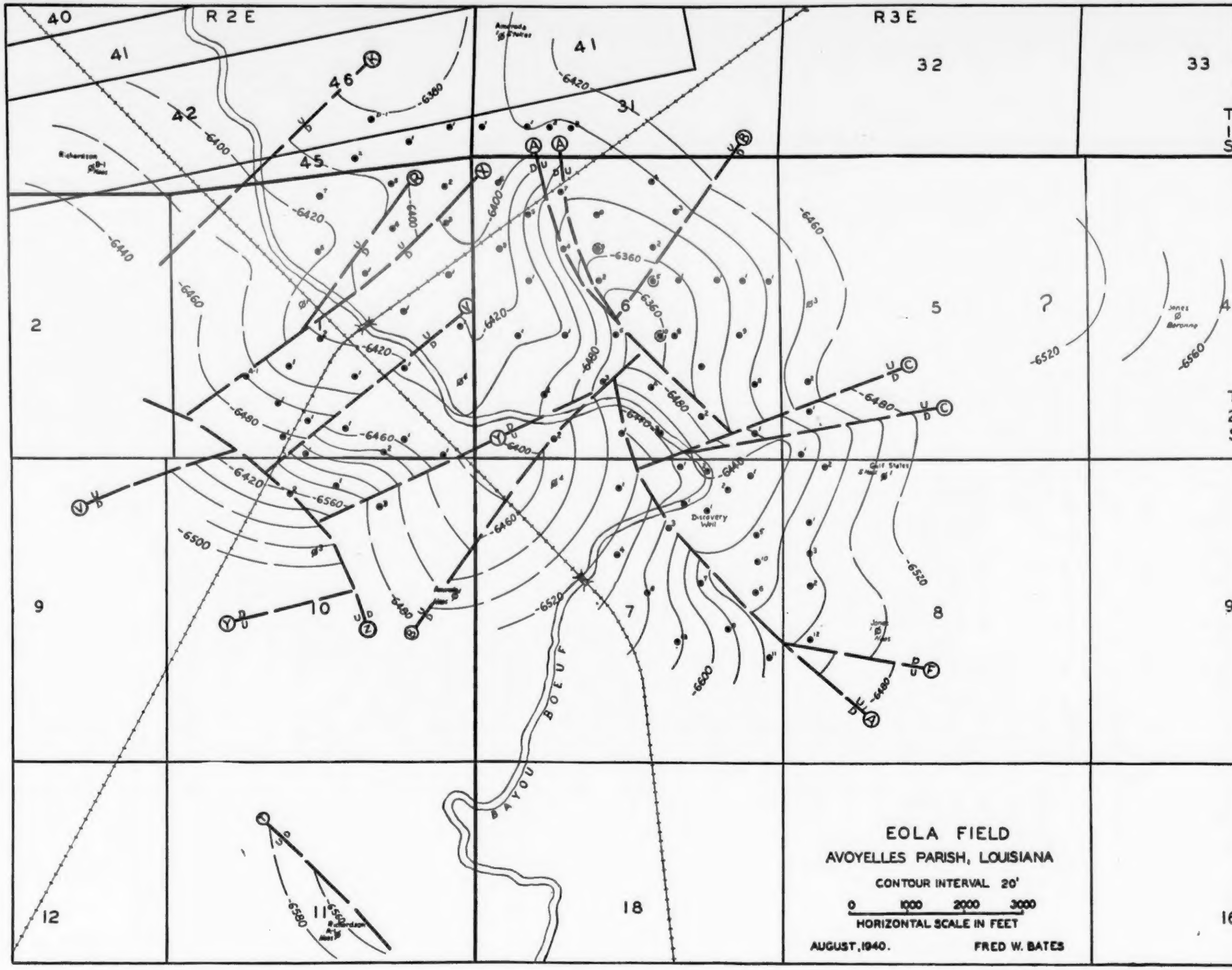


FIG. 8.—Structure-contour map of Eola drawn on sub-sea top Wilcox. All wells completed in Wilcox sand except those distinguished by double circle.

Dips outward from the center of the dome are low, between 40 and 60 feet per thousand, or about twice the regional dip of 125 feet to the mile. The total structure is greatly increased by a complex system of normal faults ranging in displacement from a few feet to over two hundred feet, with an average dip of about 50°. This faulting cuts the gently folded formations into many independent structural segments, tilted and uplifted so that although several blocks well within the field limits remain too low for commercial production, the structure as a whole is thus enhanced to the proportions of a major reservoir.

Figure 8 shows the pattern of the fault traces on the top of the Wilcox. The system consists of two major faults "A" and "Z," parallel with the main axis of folding, with "A" upthrown on the northeast and "Z" upthrown on the southwest so that a low graben area remains between. These main faults are each intersected by a strong transverse fault, "B" and "V," respectively, upthrown on the northwest. The point of intersection of each of the axial faults with its transverse fault marks the two apparent centers of disturbance, the point of greatest displacement along the main faults, and the center from which the additional minor faults radiate. All the faults die out away from these centers. The pattern is further complicated by the offsetting of "A" at its intersection with "B."

The east part of the field, the segment between "B" and the south leg of "A," is affected by the four minor radial faults "C," "D," "E," and "F." Traces radial from the western center form a series of step faults "V," "X," "R," and "K" across the graben area, each fault being upthrown on the northwest. The fault blocks closest to the center of the field in this graben thus remain the lowest structurally and account for the presence of dry holes here, surrounded by producing wells. The fault "T" cuts only the extreme southwesterly dry hole, Richardson's Haas Investment Company No. A-1, so its direction and relationship to the pattern here developed can not be accurately determined. It may, however, be a continuation of the main axial fault "Z."

Although the result of these faults is to isolate, to a greater or lesser degree, the reservoir contents of each block, as will be proved later, this effect has not apparently been active through geologic time. Readjustment of fluid levels has been accomplished, irrespective of faulting, so that the oil-water contact has become a constant plane at −8,520 feet. All Wilcox sands encountered above this depth are found to contain oil.

The saddling toward the northwest which was suggested by the geophysics is apparent on these maps although not as prominent as

FIG. 8.—Structure-contour map of Eola drawn on sub-sea top Wilcox. All wells completed in Wilcox sand except those distinguished by double circle.

in the following figures. The nosing southwest and east is corroborated by the abnormally high Wilcox tops of the dry holes located on them.

A relief model also constructed on the sub-sea top Wilcox with a vertical scale exaggerated ten times (Fig. 9) is helpful in visualizing the fault pattern and its effect on the structure. The mechanics of the series of step faults crossing the graben area becomes particularly clear through this means of representation.

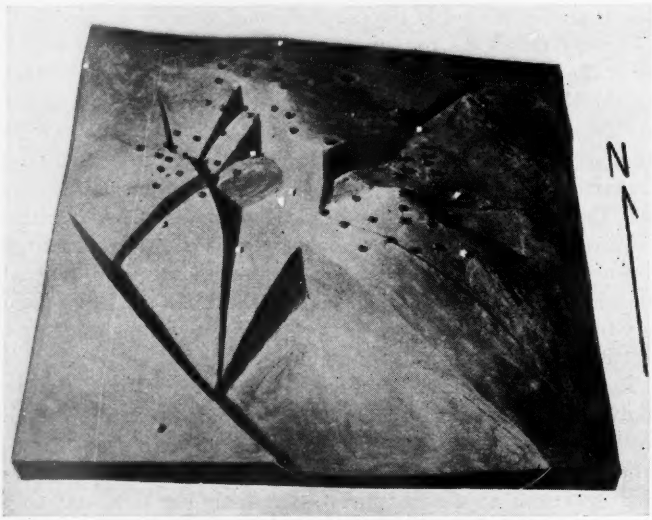


FIG. 9.—Relief model of Eola prepared on top Wilcox with vertical scale exaggerated ten times. Dry holes indicated by white squares.

As the fault planes rise through the geologic section, their displacement decreases considerably, the direction of strike repeatedly changes, and the trace on any horizon naturally shifts toward its upthrown side. The structure contours on the top Cockfield (Fig. 10) illustrate these features. The traces of the main faults "A" and "Z" have moved apart and all subsidiary faults have shifted toward their respective upthrown blocks. Bifurcation of the faults "A" and "C" is apparent, while "R" and "X" have converged.

Since the displacement of the faults is materially decreased by Cockfield time, the structure has lost its north closure and appears as a southeasterly plunging nose. The only productive areas are minor noses on the main feature cut off and tilted by the diminished faulting. The close relationship to the Cheneyville dome to the northwest be-

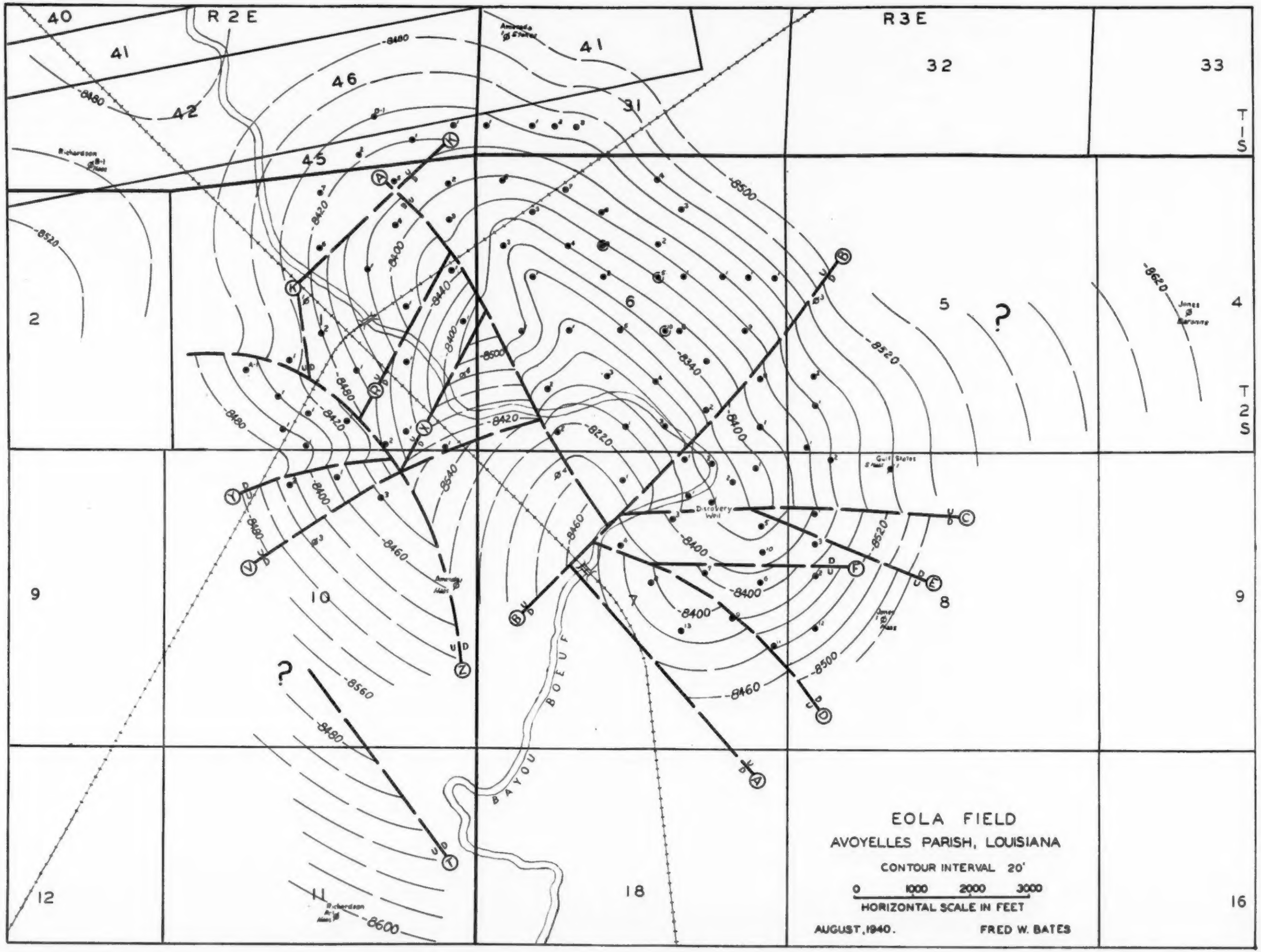


FIG. 10.—Structure-contour map of Eola drawn on sub-sea top Cockfield sand. Cockfield producers distinguished by double circle.

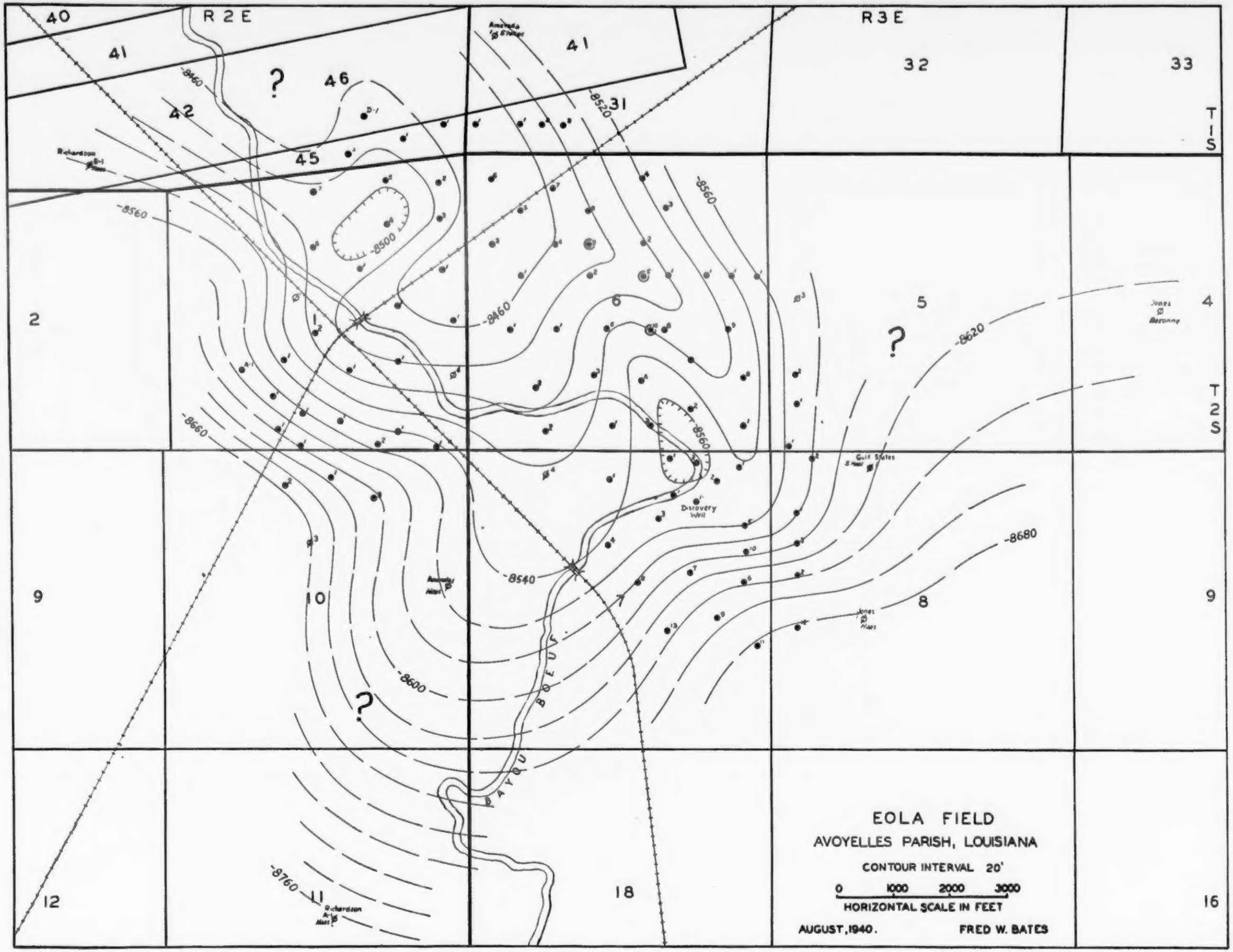


FIG. 11.—Structure-contour map of Eola drawn on sub-sea top Wilcox after compensating each well for faulting. Essentially "un-faulted" Wilcox structure.

comes increasingly evident, the east and southwest noses strongly indicated. The faulting was continuously active during Claiborne time, and decreasingly active up through the upper Eocene and Oligocene into the middle Miocene, above which its effects can no longer be detected.

ISOPACH MAPS

A map has been prepared in which the sub-sea Wilcox top on each well has been corrected for the amount of faulting noted (Fig. 11). This map can be considered as an isopach showing the true thickness of formations from sea-level to the top Wilcox, or an "unfaulted" or "pre-faulted" Wilcox structure-contour map. This figure illustrates how completely the Eola field is dependent on faulting to convert an unclosed nose into a producing closure by tilting of the component fault blocks.

The center of the folded structure now appears in the northwest corner of Section 7, which, it will be noted, is in the lowest part of the graben on the faulted Wilcox structure. The low or thick area on the line between Sections 6 and 7 is apparently a result of thicker sedimentation on the down side of fault "B" at its point of greatest displacement; it corresponds in position with the downdropped block shown on the Cockfield map. The low area in the NE. $\frac{1}{4}$ of Section 1 is a combination of thicker sedimentation on the field's northwest-limiting saddle, and on the low side of the transverse fault "K" the two noses are again strongly indicated.

The true isopachs constructed on intervals from Cane River to Wilcox, Cockfield to Cane River, and Vicksburg to Cockfield show that the growth of structure was gradual and continuous through these periods. A maximum thinning over the field of 16 per cent in the first interval indicates that the greatest recorded structural growth occurred during this period; thinning of 7 per cent during the second interval suggests relative quiet during Cockfield-Cane River time, while an increase to 15 per cent during Vicksburg-Cockfield time indicates a rejuvenation of uplift. Since thinning of the sea-level-Wilcox interval is but slightly more than the total thinning noted during Vicksburg-Wilcox time, it is evident that little uplift could have occurred later than the end of the Oligocene. The slight relief shown at the Vicksburg and *Heterostegina* tops can be attributed to the weak persistence of faulting into Miocene time.

The three isopachs in general show upstructure thinning with a slightly heavier deposition in the center. This picture is influenced by the occurrence of thick sections on the downthrown sides of the traces

FIG. 11.—Structure-contour map of Eola drawn on sub-sea top Wilcox after compensating each well for faulting. Essentially "un-faulted" Wilcox structure.

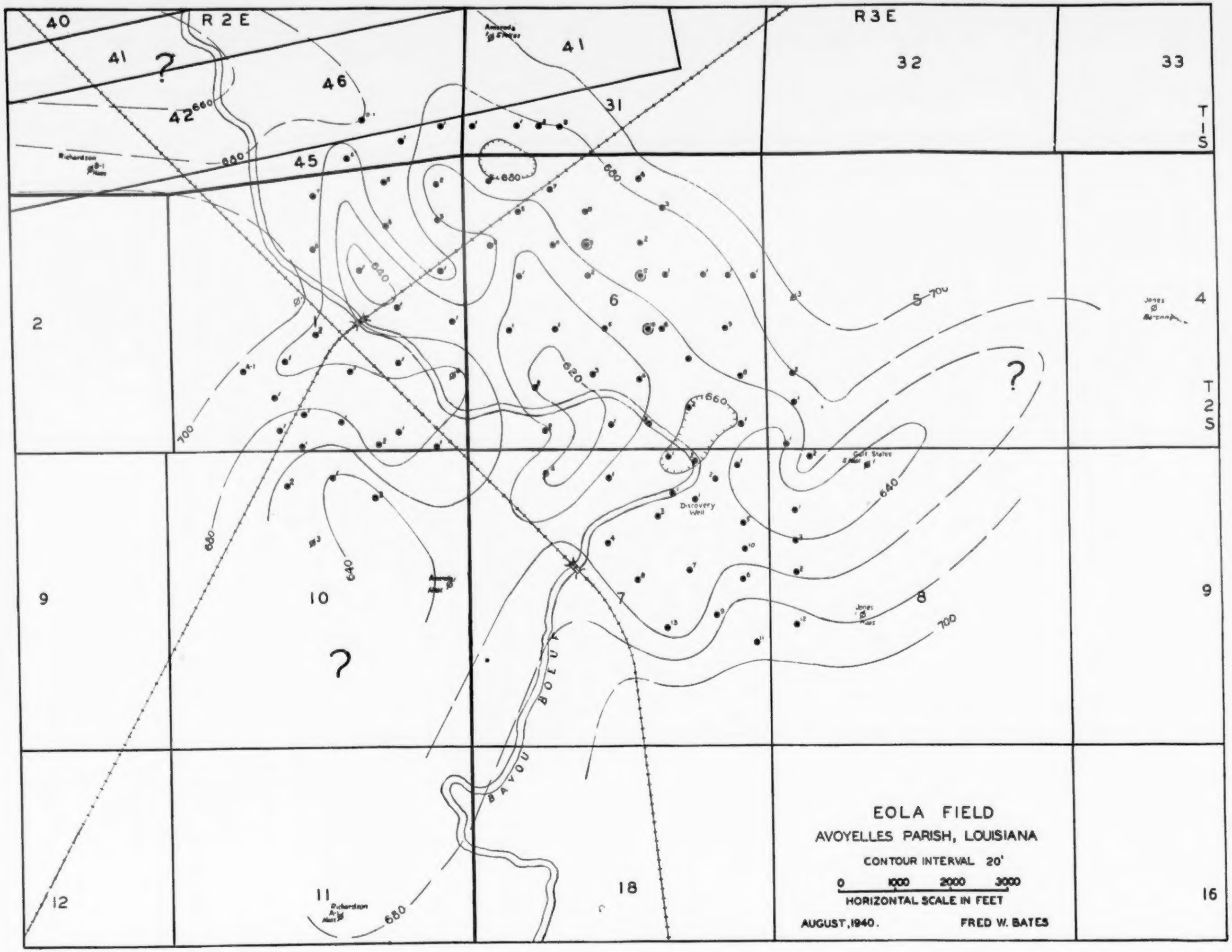


FIG. 12.—Isopach map of Eola field drawn on interval between top Cane River and top Wilcox.

FIG. 12.—Isopach map of Eola field drawn on interval between top Cane River and top Wilcox.

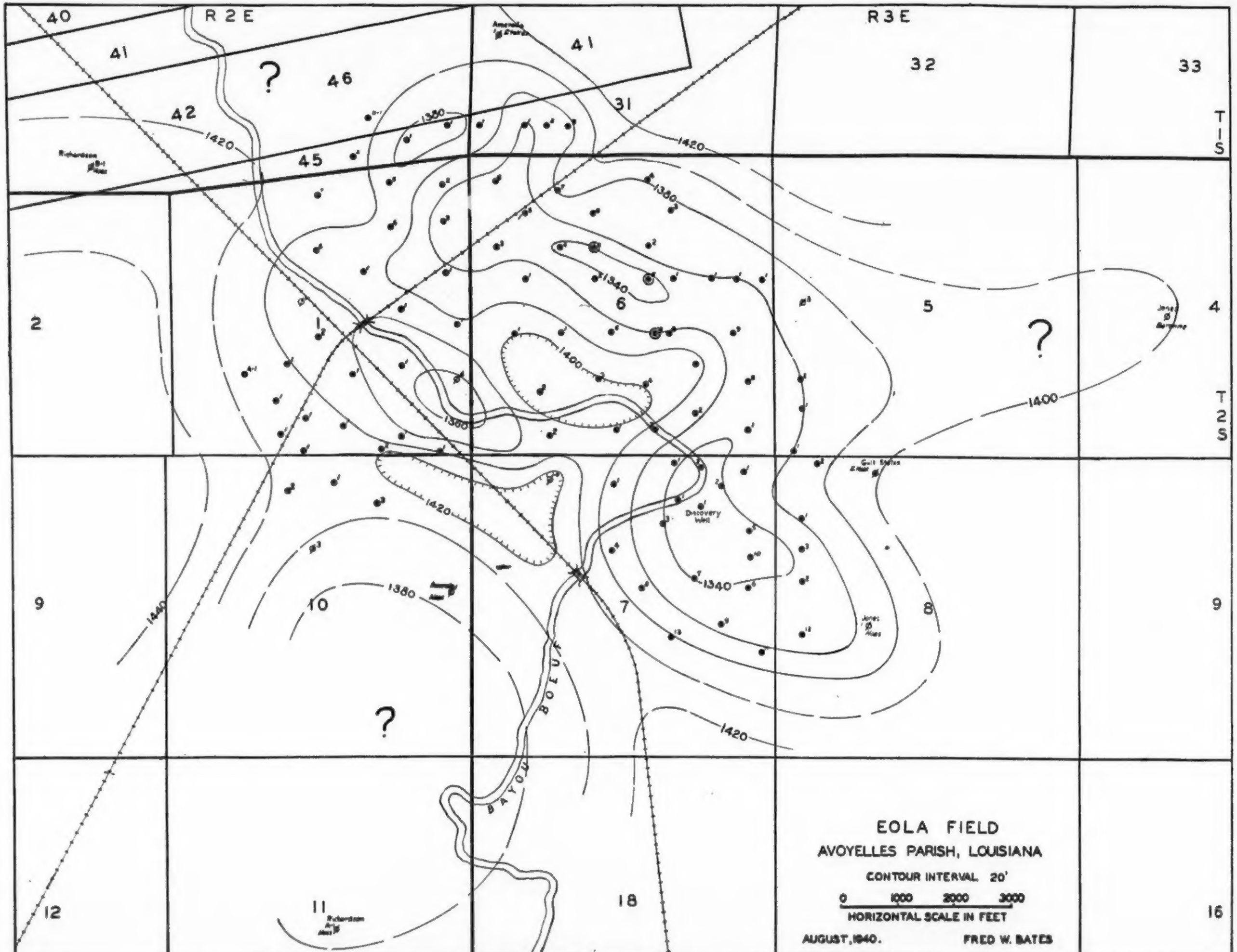


FIG. 13.—Isopach map of the Eola field drawn on interval between top Cockfield and top Cane River.

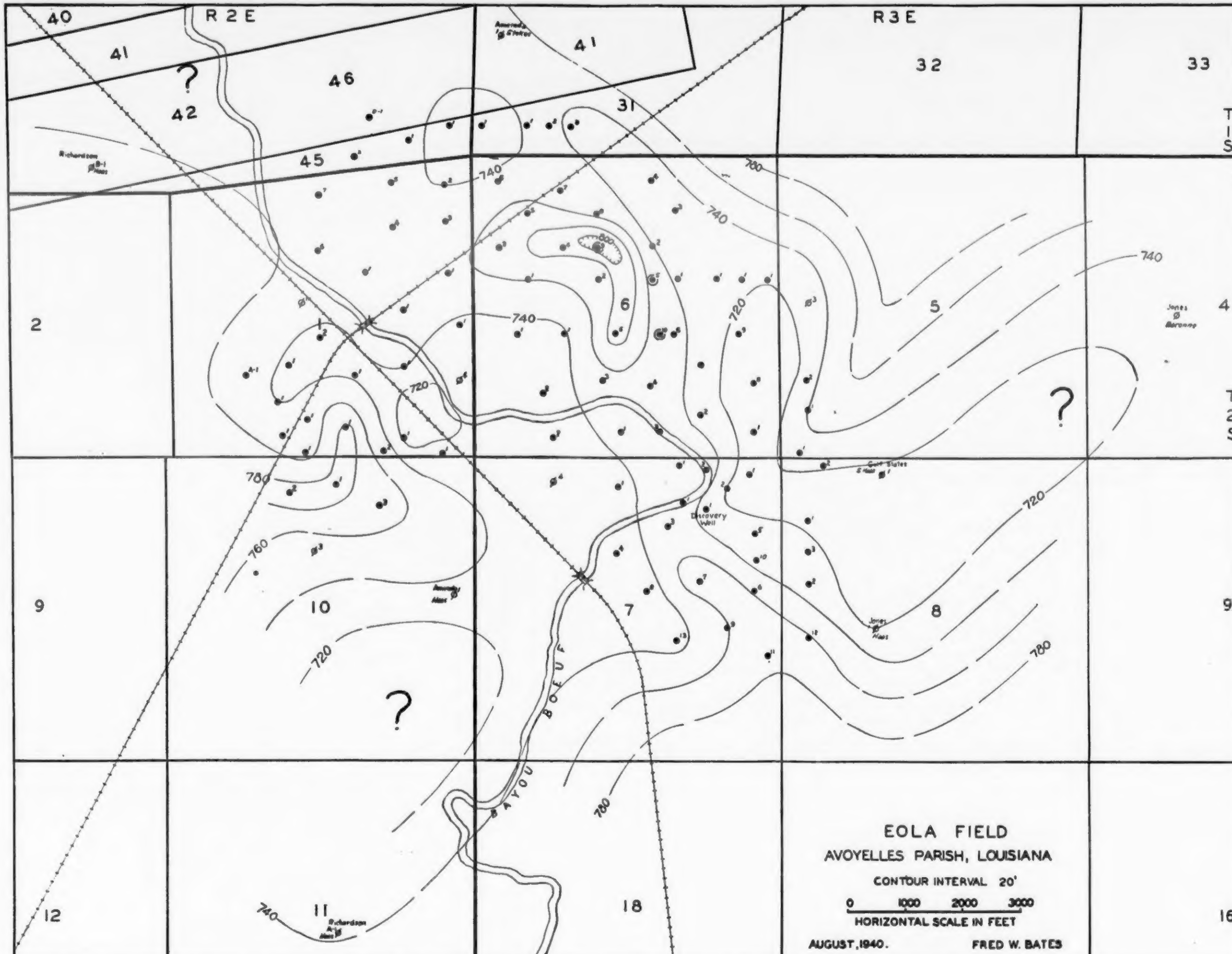


FIG. 14.—Isopach map of Eola field drawn on interval between top Vicksburg and top Cockfield.

of the larger faults during each interval, or over depressed blocks.

The Cane River-Wilcox interval shows a prominent thin section over the southwest nose. A similar decrease in sedimentation is noted over the easterly nose, extending west to include the parts of the fields upthrown by fault "A." Thicker deposition in the southeast corner of Section 6 is caused by downwarping along fault "B." Thickening of section on the downthrown side of fault "A" is evidenced by re-entrants in the northeast corner of Section 1 and the southwest of Section 7. The thick section in the southeast corner of Section 1 lies partially over the deeper part of the graben area.

Features noted in the older interval persist into Cockfield-Cane River time, with increased evidence of thickening over the graben.

The Vicksburg-Cockfield interval naturally shows its greatest shortening over the top of the Cockfield structure in the west-central part of the field. Since this corresponds with the position of the lowest part of the Wilcox graben, it is apparent that the faulting causing this depressed area was probably strongest in early Claiborne time and its effects are largely offset by the thickened sedimentation noted above in pre-Cockfield deposits over this portion of the field. A very thin section is noted over the southwest nose. An equally thin section over the east nose again extends to include the portions of the field upthrown by fault "A." A thick section in the north-central part of the field lies both on the north-east flank of the Cockfield nose and on the downthrown side of the Cockfield trace of fault "A."

PRODUCTION DATA

All wells at Eola were drilled with rotary tools, usually in slightly less than 30-days. Ten and $\frac{3}{4}$-inch surface casing has been set at about 1,500 feet to shut off fresh-water flows; and to prevent the contamination of these sands, excessive loss of drilling fluid, or caving of the soft sands and gravels above this depth. A $5\frac{1}{2}$-inch oil string has been set, in most wells, through the sand and gun-perforated for production through 2-, or $2\frac{1}{2}$-inch tubing.

The Eola field produced to December 1, 1940, a total of 4,561,544 barrels of 43° A. P. I. gravity crude of paraffine-intermediate base, with little salt water. Small amounts of paraffine and gas-cut emulsion are produced, or deposited in the tubing. Figure 15 is a chart prepared by the Minerals Division of the Louisiana Department of Conservation showing monthly and cumulative production, bottom-hole pressure and decline, and other data pertinent to the production from Eola field. Tables I and II below give two detailed analyses of this crude.

FIG. 14.—Isopach map of Eola field drawn on interval between top Vicksburg and top Cockfield.

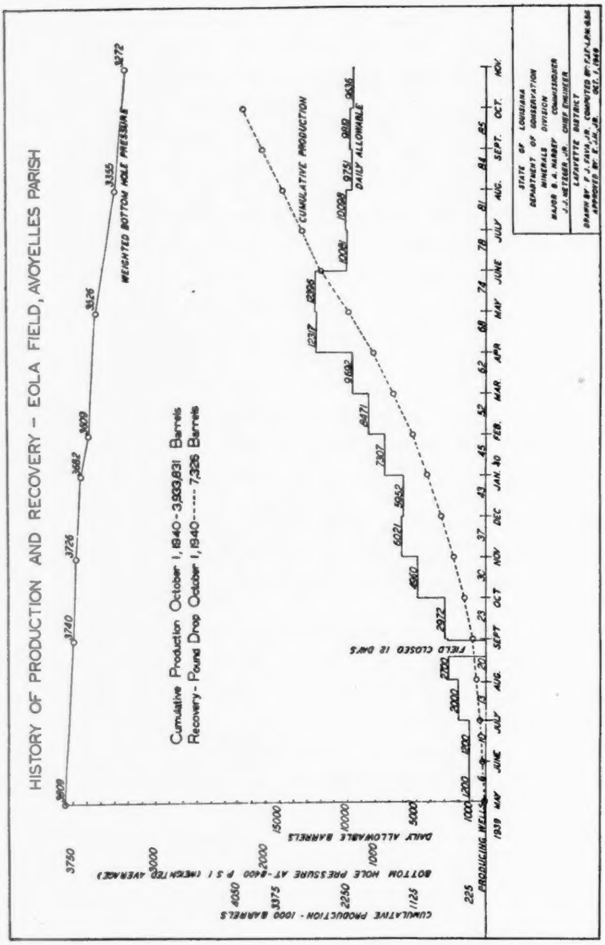


FIG. 15.—Chart of Eola production data prepared by Minerals Division of Louisiana Department of Conservation.

TABLE I

CRUDE ANALYSIS BY SUN OIL COMPANY OF OIL FROM HAAS INVESTMENT COMPANY NO. 1

A.P.I. gravity	44.4° @ 60°F.
	Percentage
Paraffine	3.75
Sulphur	0.04
Gasoline	38.41
Kerosene-distillate	17.03
Bottoms	42.31

TABLE II

CRUDE ANALYSIS BY U. S. BUREAU OF MINES OF OIL FROM HAAS INVESTMENT COMPANY NO. 1

Base	Paraffine intermediate
	Percentage
Sulphur	Less than 1.0
Carbon residue	4.0
Gasoline and naphtha	34.9
Kerosene-distillate	18.1
Gas-oil and heavier distillate	30.1

Working tubing pressures range from 1,300 to 1,800 pounds with some wells showing lower or higher extremes. Normal gas-oil ratios are between 1,100:1 and 1,600:1. Potential tests are made monthly by the operators and witnessed by the Louisiana Department of Conservation, normally averaging between 250 and 330 barrels per day on 3/16-inch chokes in November, 1940.

Wells on the extreme southwest side show slightly different production characteristics than in the remainder of the field indicating, as before mentioned, complete isolation by faulting of this accumulation from that of the rest of the field. These wells show higher working pressures, and gas-oil ratios up to 2,000:1. The gravity of the oil is several degrees higher and little paraffine or emulsion is noticed.

These data are applicable only to Wilcox wells. The three Cockfield producers show potentials of between 200 and 250 barrels of 36° A. P. I. gravity crude per day with working tubing pressure of about 700 pounds and gas-oil ratio of 350:1.

Oil is taken from the field by pipe-line of the Standard Oil Company of Louisiana to water transportation and refineries at Baton Rouge, Louisiana. Quotation by this company for crude purchases for November, 1940, was $1.09 per barrel.

Bottom-hole pressures.—Pressures have been determined quarterly by the individual operators with supervision by the Minerals Division of the Louisiana Department of Conservation. First bottom-hole pressures taken in May, 1939, were about 3,800 pounds; the normal pressures in November, 1940, ranged between 3,200 and 3,400 pounds,

with up to 3,500 pounds on the extreme southwest across fault "Z." Cockfield bottom-hole pressure is now about 2,800 pounds.

The pressure decline seems rather high considering the small proportion of the available oil withdrawn. However it must be remembered that this is not a true measure of the rate of drop for the future life of the field since most of the wells have been in production a comparatively short time and have not yet settled down to their normal flowing characteristics. Also many of the early wells were allowed to produce at rates in excess of the optimum, which undoubtedly brought about a considerable loss of reservoir energy. More complete statistics, prepared over a period of years, will be necessary before conclusions can be drawn as to the probable flowing life of the field.

The actual values of bottom-hole pressure, and the relative rates of decline in different wells, furnish a valuable check on the fault patterns developed in the previous discussion. Where any well or group of wells shows a substantial difference in values of bottom-hole pressure or decline, compared with adjacent wells, it may be safely assumed that the reservoirs of the two groups are separated, partially or entirely, from each other, probably by faulting.

J. Davis Collett, petroleum engineer of Houston, Texas, has made many of the pressure determinations and kept close and accurate records of the results. The following statement is his personal communication to the writer in October, 1940.

> We have substantiated practically all of the faulting shown on your subsurface map in so far as these affect reservoir conditions, and with relation to transfer of content, and pressure equalization.

Maps contoured by Collett on values of bottom-hole pressure closely approximate the one here submitted contoured on sub-sea top Wilcox (Fig. 8). The few faults he was unable to substantiate are minor, of 30 feet displacement or less, which do not prevent migration of reservoir content through the thicker sands, and hence would allow equalization of pressures. He suggests several of the minor faults do have a secondary effect, acting "more as a choke or restriction, than an actual seal."

In general the larger segmental fault blocks (such as the one on the northeast of the field between faults "A" and "B") having their apex at or near the top of the dome, bounded by radial faults, and with free access to the downdip limits of structure will show no effect of faulting in their pressure characteristics. They will flow by a strong combination of gas expansion and water drive, and will have the longest flowing life. Portions of such segments which are cut off by strike faulting

from water drive from the lower extremities of the structure will produce by gas expansion only. Sealed-off portions lower on structure with availability to water drive will produce by this latter means entirely. Minor faulting will produce reservoir conditions intermediate between these three types.

Proration.—Allocation of the total field allowable to individual leases and wells is made by the Louisiana Department of Conservation. This is based on 20-acre drilling units, with a division of 50 per cent of total allowable to per-well acreage, 25 per cent to the individual potentials and 25 per cent to bottom-hole pressure. Tests are made monthly by the operators on each well and the allowable production computed from these figures for the following month.

The total daily allowable for the field for December, 1940, was set at 9,800 barrels. The average per-well allowable for this period was 101 barrels; the average allowable considering only wells on full 20-acre units was about 120 barrels.

ESTIMATE OF RESERVES

In estimating reserves at Eola, figures for probable per-acre-foot recoveries have been taken from computations of Core Laboratories, Inc. of Dallas, Texas, made from detailed analyses of cores for porosity, permeability, oil saturation, volume of dissolved and free gas, and connate water content. Although these analyses were not made on each well at Eola, a sufficient number have been made here and in other similar fields to afford an accurate basis for estimation (Fig. 6). The values used for each sand are an empirical combination of the recovery by gas expansion and by water drive.

The probable original ultimate recovery from the Cockfield sand is placed at 2,400,000 barrels; from the Sparta, 8,800,000 barrels; from the Wilcox, 48,900,000. The total original reserve for the field is 60,100,000 barrels.

CONCLUSION

Geophysics exclusively may be accredited with the discovery of the Eola field. It effectively outlined the productive area, but was insufficient to delineate the complex faulting or foretell its results.

The structure is apparently a large gentle nose so affected by tilting and uplift along numerous fault planes that a considerable amount of closure is thus introduced.

Eola may be considered one of the major petroleum reserves of the Gulf Coast area as a total ultimate recovery of more than 60 million barrels is indicated, of which only a very small part has been recovered to date.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 25, NO. 7 (JULY, 1941), PP. 1396–1404, 4 FIGS.

CLASSIFICATION OF THE ARTINSKIAN SERIES IN RUSSIA[1]

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ABSTRACT

The name Artinskian has been applied in Russia to (1) a series of clastic rocks lying immediately east of the outcrop of the *Schwagerina* limestones of the Ufa Plateau, (2) rocks of similar facies in the western Urals, equivalent to these and older limestones, and (3) the *Schwagerina* limestones. The first, more than 1,000 meters of shales, sandstones, and conglomerates, seem younger than the *Schwagerina* limestones; Murchison's definition of the Permian system refers these clastic rocks to its base, and the city of Artinsk lies in their belt of outcrop.

The principal uplift of the Uralian orthogeosyncline followed the formation of the *Schwagerina* limestones on the Russian platform; the younger Artinskian sediments formed in a geosyncline within the margin of the platform. There was marine withdrawal from the interior during Artinskian time; younger, Kungurian sediments overlap on pre-Artinskian limestones.

INTRODUCTION

The younger sediments of the Ural Mountains region are of peculiar interest because they include the classic sections on which the Permian system was founded. American geologists were among those privileged to study some of the typical exposures on an excursion of the International Geological Congress in July, 1937. A review of some of the impressions gained has been presented by C. O. Dunbar.[3] The following discussion presents a differing understanding of the relations of the Artinskian clastics to the limestones of the Ufa Plateau, the "Artinskian series" of Dunbar; it is based principally on statements in the guidebooks, and conversations with Russian geologists. There is realization that shortcomings in available information lead to differing conclusions that might not arise if more facts were available.

STRATIGRAPHY

The term "Artinskian" has been applied to both facies and time in Russia. The Carboniferous *Triticites*-bearing limestones of the western Ufa Plateau (Fig. 1) are succeeded by limestones containing *Pseudoschwagerina*—the Sakmarian series of Ruzencev. That both are represented in beds of Artinskian *facies*, that is, in shaly formations, in the western Urals in the latitude of Ufa was shown at Sim Works,[4]

[1] Manuscript received, December 12, 1940.

[2] Assistant professor of geology, Columbia University.

[3] C. O. Dunbar, "The Type Permian: Its Classification and Correlation," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24 (1940), pp. 237–81.

[4] D. V. Nalivkin, "The Sim Works," *Guidebook Permian Excursion, Southern Part, XVII Inter. Geol. Congress* (1937), pp. 123–31.

and verified by Dunbar's subsequent study of the collected fusulinids. The *Pseudoschwagerina* limestones of the plateau are overlain by those bearing species of *Schwagerina*, *S. lutugini* (Schellwien) being characteristic of their upper part; these are believed to be equivalent also to beds of Artinskian facies in the southern Urals. There is compelling evidence that there are clastics of "Artinskian" facies in the Urals that are equivalent to limestones of the plateau.

The great series of clastics in the broad syncline east of the plateau in the latitude of Perm and Kungur seems, however, to be younger than the limestones bearing *S. lutugini*. These are in the type area of the Permian, as well as in the belt in which Artinsk lies, and it would seem more appropriate to classify them as the Artinskian series than apply the name to the older limestones of the plateau.

That the Artinskian sediments lying between the Ufa Plateau and the folded and faulted Urals are younger than the *Schwagerina* limestones is shown in sections along the Trans-Siberian (Kaganovitch) Railroad east of Kungur, and in the Kizel district, 125 kilometers north. For 140 kilometers from Shumkovo, east of Kungur, to Buloga, the railroad crosses an essentially west-dipping homocline.[5] The oldest beds, at the east, are the "lower Artinskian" (Fig. 2A), comprising 250–350 meters of shale beneath more than 100 meters of conglomerate. The latter bears pebbles to "9.5 m." (*sic*, possibly 9.5 cm.) in diameter of quartz, tuffaceous rocks and limestones, the latter having fragments of lower, middle and upper Carboniferous, and including some stated to contain *S. lutugini*, the characteristic fossil of highest limestones of the plateau. More than 1,000 meters of younger Artinskian clastics contain alternating marine invertebrate and plant-bearing beds, and vividly displayed contorted inter-beds of mud-flow character. The youngest Artinskian beds are exposed nearly 100 kilometers west of the oldest.

In the Kizel district, more than 350 meters of *S. lutugini*-bearing limestone is succeeded "without apparent unconformity" by 430 meters of Artinskian shaly sandstone and overlying conglomerate, the sandstones bearing the rich cephalopod faunules studied by the excursion on the Kosva River (Fig. 2B).[6]

Clastic rocks of Artinskian facies are absent along the Sylva River east of Kungur, the calcareous dolomite series of the lower Kungurian lying in "transgressive superposition of the eroded surface of the under-

[5] M. M. Tolstikhina, "Kuzino to Perm," *Guidebook Permian Excursion, Northern Part, XVII Inter. Geol. Congress* (1937), pp. 34–57.

[6] I. I. Gorsky, "Chusovaya to Solikamsk," *Guidebook Permian Excursion, Northern Part, XVII Inter. Geol. Congress* (1937), pp. 75–80.

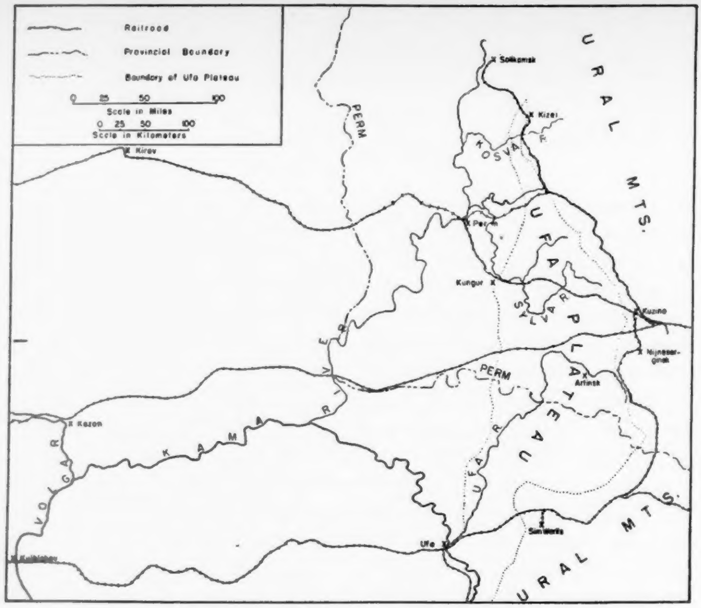

FIG. 1.—Outline map of part of eastern Russia.

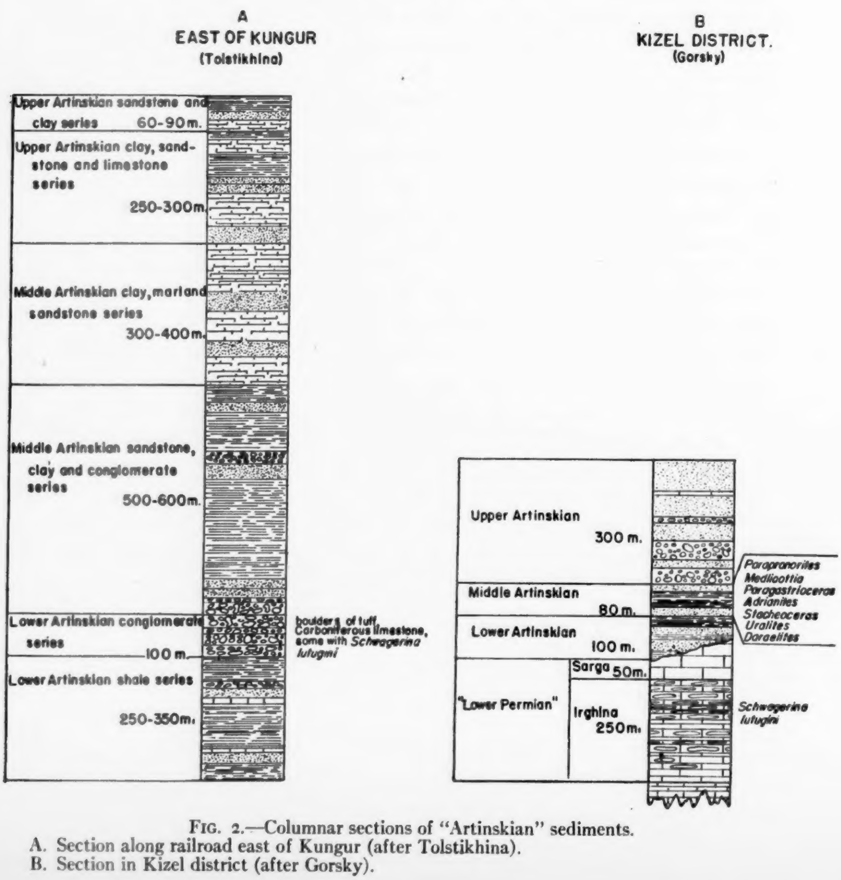

FIG. 2.—Columnar sections of "Artinskian" sediments.
A. Section along railroad east of Kungur (after Tolstikhina).
B. Section in Kizel district (after Gorsky).

lying [*S. lutugini*] limestone series, in which it fills up considerable unevenness of relief."[7] Some Russian geologists believe that the upper Artinskian, described as sandstones and clays enriched westward "in carbonate and halogenous formations," and with thickness varying from 60 to 90 meters, grades westward into the lowest Kungurian, an apparently reasonable interpretation. It does not seem probable to the writer that the coarse clastic Artinskian, with interrelated marine shales, can have graded directly into the thick Kungurian salines, however. If the relations are properly understood, the disconformity between the Kungurian and the *Schwagerina* limestone in the Ufa Plateau represents the time in which a great thickness of clastic Artinskian was laid in a geosyncline within the eastern margin of the Russian platform, the lower Kungurian subsequently overlapping the limestones westward.

The Kungurian series composed considerably of salts such as those mined at Solikamsk occupies a broad belt west of the Ufa Plateau. It is in turn overlain by the Kazanian series composed in the east of red non-marine terrigenous sediments that gradationally overlap the *Spirifer* and *Conchifera* marine sediments in the region of the lower Kama and Volga rivers. These are in turn overlain by the red clastic Tartarian series.

Thus, the chronology can be expressed as follows.

Tartarian
Kazanian
Kungurian
Artinskian of region between Sylva River and Ural Mountains
Schwagerina zone, "Artinskian" of Dunbar, classified as "Upper Carboniferous," "Lower Permian" or "Lower Artinskian" by Russian geologists
Sakmarian—the *Pseudoschwagerina* zone
Triticites zone

The *Schwagerina* zone comprises the upper part of the Uralian series of De Lapparent, which included older beds in addition; it would be confusing to use the term Uralian in a restricted sense, but the designation of these beds as the Artinskian seems similarly inappropriate. The problem seems to be one of whether the *typical* Artinskian is a series entirely younger than the limestones, or one of which the *lower part* is equivalent to the limestones. Inasmuch as the writer believes that the principal structural break succeeds the limestones, and precedes a large part or the whole of the typical Artinskian, he disfavors the reference to one series of both the limestones and the younger clastics. Thus, the *Schwagerina* limestone could bear advantageously a distinct series name, if they constitute a series, one which could be applied by someone active in their study.

[7] M. M. Tolstikhina, *op. cit.*, p. 50.

PALEOGEOGRAPHY

The sediments of eastern Russia are interpreted as evidencing the following history (Fig. 3). In late Carboniferous and Sakmarian time, limestones were laid on the Russian platform, extending east to a geosyncline in about the present position of the folded and overthrust Ural Mountains; the succeeding offlapping *Schwagerina* limestones had similar distribution. Though there are clastic sediments equivalent to the limestones in the southern Urals, the limestones seem to continue into the mountains in the latitude of Perm.

Uplift of the Uralian geosyncline followed, with production of the typical Artinskian clastics, which were laid in a new geosyncline on the border of the preceding platform. Rapid subsidence of the part of the platform east of Kungur followed deposition of the *Schwagerina* limestone, and accompanied the incursion of "clastic terrigenous sediments of the Artinskian, evidencing uplifting of the Ural Mountains and their regional erosion."[8] The lower Artinskian conglomerates include pebbles or boulders of quartz, and of tuffaceous rocks, such as are present in the Silurian sediments within the Ural thrust sheets near Nijneserginsk,[9] in association with pillow-lavas, and cherts which when sectioned by the writer were found to bear radiolarians. The pebbles can be interpreted as derived from the uplift of the Uralian orthogeosyncline[10] to the east of their place of deposition. The presence of the limestone boulders implies that carbonates as young as the *Schwagerina lutugini* zone extended into the orthogeosyncline in the latitude of Kungur. These structural events were accompanied by withdrawal of seas from the interior of the platform, possibly eustatic lowering accompanying the orogeny.

That there had been movement along the margin of the orthogeosyncline in pre-Artinskian time is evidenced in the boulder conglomerates of the Sim Works district. The Domenaya breccia[11] has been interpreted as a landslide deposit. In position and character it may be analogous to the conglomerates of the northern Ouachita Mountains, recently interpreted as erratics derived from a thrust sheet having its sole in the foreland of the Ouachita geosyncline.[12]

[8] I. I. Gorsky, *op. cit.*, p. 85.

[9] B. V. Nalivkin, "The Ufa Amphitheatre," *Guidebook Permian Excursion, Northern Part, XVII Inter. Geol. Congress* (1937), pp. 11–12, 26.

[10] H. Stille, "Der derzeitige tektonische Erdzustand," *Preuss. Akad. Wiss., Phys.-Math. Klasse*, XIII (1935), p. 6; also *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20 (1936), p. 853.

[11] D. V. Nalivkin, *op. cit.*, pp. 127–28; C. O. Dunbar, *op. cit.*, pp. 246–47.

[12] T. A. Hendricks, "Structure of the Western Part of the Ouachita Mountains" (abstract), *Program 25th Ann. Meeting Amer. Assoc. Petrol. Geol.* (1940), p. 35.

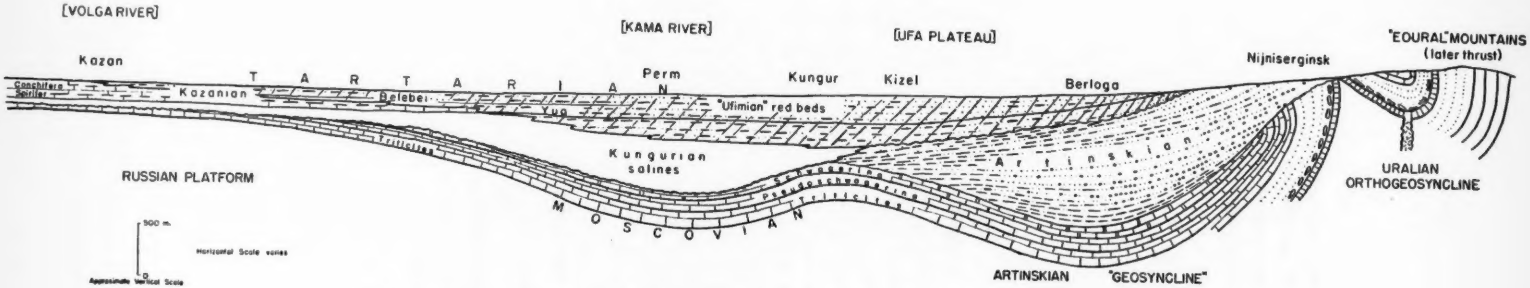

FIG. 3.—Restored section of later Carboniferous and Permian sediments at close of Kazanian epoch.

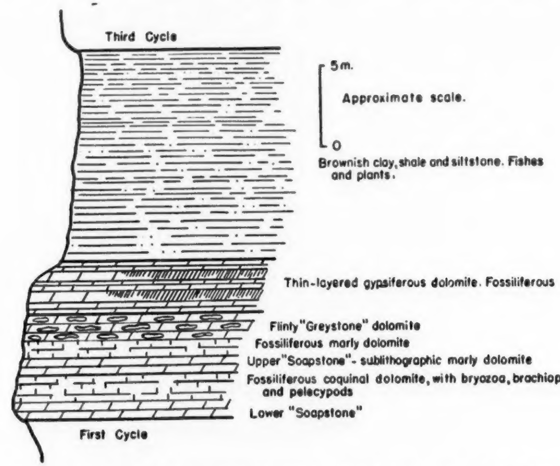

FIG. 4.—Second of three cyclothems in *Conchifera* beds south of Kazan (after field notes and Noinsky).

Kungurian sediments include thick saline deposits, and were laid along the western margin of the Artinskian plains, overlapping the limestones of the platform. The succeeding Kazanian series shows continental gradational overlap westward of red clastic sediments over the *Spirifer* and *Conchifera* marine zones of the interior, reflecting renewed uplift of the Ural region and retreat of seas before the advancing continental sediments. There are three cyclothems in the *Conchifera* beds at Kazan (Fig. 4).[13] The Kazanian is followed by the wholly continental Tartarian series, considerably composed of redbeds. The later Permian red sediments are related to the marine in a manner comparable with that of the Ordovician Juniata-Queenston redbeds to the marine Richmond, or of the Catskill facies to the marine sediments of the later Devonian in the Allegheny synclinorium.

PROBLEM OF CARBONIFEROUS-PERMIAN BOUNDARY

The placement of the base of the Permian system is dependent on the criteria that are considered most significant. If the base of the Sakmarian is in other regions marked by distinctive faunas, and overlies important disconformities and unconformities, that would be a significant factor in designation. But in eastern Russia, great foreland disconformity and regional unconformity separate the *Schwagerina* beds from the Kungurian, and there was important synchronous orogenesis in the Uralian orthogeosyncline, producing the Artinskian clastic sediments. The significance of the event has been emphasized by Fredericks,[14] who considered the top of the limestone series to mark the base of the Permian system; he believed the *Schwagerina* beds to have been laid prior to regression, uplift and erosion, the building of the "Eo-Urals," and Artinskian transgression and sinking. Grabau[15] supposes the break to follow the Kungurian, and places the boundary between his Uralinskian and Permian systems higher; in the manner in which his other pulsation systems are separated, the Kungurian would seem more logically to form part of the transgressive phase of a Permian system.

The placement of the boundary presents a problem analogous to that of the base of the Pennsylvanian in the American Mid-Continent region. The influx of orthogeosynclinal clastics into the Artinskian

[13] M. Noinsky, "Contributions on the Structure and Facial Characters of the Kazanian in the Region of Kazan," *Bull. Comité Geol. Leningrad*, Vol. XLIII, No. 6 (1924), pp. 565–622.

[14] G. Fredericks, "Revisions in the Upper Paleozoic Stratigraphy of the Urals," *Soç. Russe Miner. Mem.*, Vol. 62, No. 1 (1933), pp. 57–70; "The Upper Paleozoic of the West Slope of the Ural," *Trans. Geol. Prosp. Service U.S.S.R.*, Fasc. 106 (1932).

[15] A. W. Grabau, *The Rhythm of the Ages*, p. 520. Peking (1940).

parageosyncline (in the sense of Stille) is comparable with the invasion of Ouachita-derived geosynclinal sediments into the base of the Strawn in the Oklahoman geosyncline. This effect of the Ouachita orogeny has been thought of sufficient importance to justify the placement of the base of Pennsylvanian at this position[16] within the Pennsylvanian system of most geologists. Grabau considers it to mark the base of his Uralinskian system.

Murchison originally stated that the great tract of limestone of the "carboniferous system is surmounted, to the east of the Volga, by a vast series of marls, schists, limestones, sandstones and conglomerates, to which I propose to give the name of "Permian System."[17] From the Volga east to the Ufa Plateau, the Kungurian and younger sediments succeed the limestones, and the Artinskian clastic rocks are absent. In a later report, Murchison states that the system was first suspected on his ascent of the Dwina River, but that "as the beds are there very horizontal, we shall appeal to that section . . . in corroboration only of the succession which is more clearly exhibited on the west flanks of the Ural Mountains."[18] In the succeeding paragraph, "The oldest beds of this system, which succeed to the upper carboniferous strata, are well developed to the east of the city of Perm, on the banks of the rivers Sylva, Babka, Sira and Gromotucha, where they consist of finely laminated calcareous flagstones," clearly the Kungurian as exhibited east of Kungur on the Sylva River. Thus, in the first designation of the base of the system east of Perm, the *Schwagerina* limestones, which lie with erosional unconformity beneath the Kungurian, were classified as "carboniferous," and the Kungurian as the "oldest beds" of the Permian system. However, the older Artinskian clastics to the east, not represented beneath the Kungurian on the Sylva, were also included in the Permian system in later pages in the report, as well as rocks such as those at Sim Works outside the "kingdom of Permia" that are now known to be equivalent to the *Schwagerina* and older limestones.

In conclusion it is the writer's impression that the principal structural event within the later Paleozoic of eastern Russia followed the

[16] R. C. Moore, "'Carboniferous' Rocks of North America," *Compte Rendu XVI Inter. Geol. Congress*, Vol. 1 (1936), pp. 593–616;
B. H. Harlton, "Stratigraphy of the Bendian of the Oklahoma Salient of the Ouachita Mountains," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 22 (1938), pp. 852–914;
M. G. Cheney, "Geology of North-Central Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24 (1940), p. 75.

[17] R. I. Murchison, "First Sketch of Some of the Principal Results of a Second Geological Survey of Russia," *Philos. Mag.*, Ser. 3, Vol. 19 (1841), p. 419.

[18] R. I. Murchison, E. de Verneuil, and A. von Keyserling, *The Geology of Russia in Europe and the Ural Mountains* (1845), p. 142.

deposition of the *Schwagerina* zone and preceded the formation of the Artinskian clastic sediments in the Ufa Plateau east of Perm. There was synchronous marine withdrawal from the Russian platform. The original usage of Murchison refers the *Schwagerina* beds to the Carboniferous and subsequently includes the Artinskian rocks that lie farther east in the Permian system. If the definition of the base of the Permian system is dependent on original designation or upon inorganic history in the type region it should place the boundary above the *Schwagerina* zone and beneath the Artinskian succession east of Perm.

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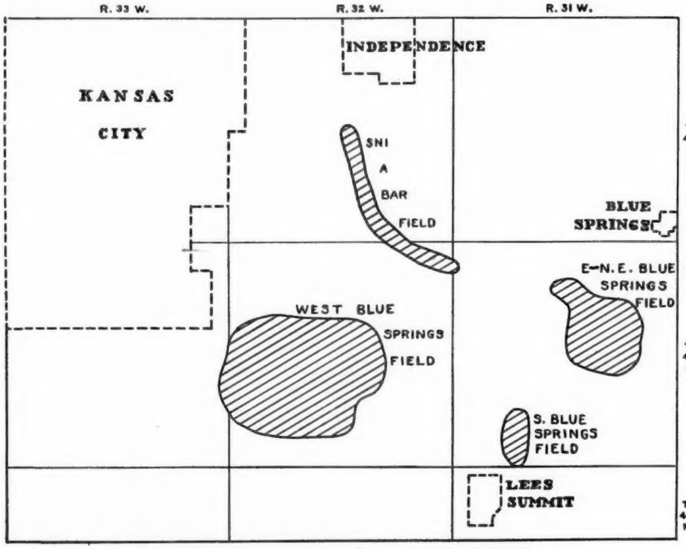
VOL. 25, NO. 7 (JULY, 1941), PP. 1405-1409, 1 FIG.

GEOLOGICAL NOTES

EFFECTIVE POROSITY OF GAS FIELDS IN JACKSON COUNTY, MISSOURI[1]

GLENN G. BARTLE[2]
Kansas City, Missouri

The Blue Springs gas field, in east-central Jackson County, Missouri, only 10 miles from Kansas City, has been described as to stratigraphic and structural geology,[3] but a final report of the production statistics with a discussion of the effective porosity of the gas-bearing



Location of the Western Jackson County Gas Fields.
GLENN G. BARTLE, GEOLOGIST

formation may be in place at this time. The field, now about 12 years old, is almost exhausted and the production figures for each district may be accepted as within the last one per cent of the total recovery of the field.

The East and Northeast Blue Springs field, comprising 2,080 acres,

[1] Manuscript received, April, 1941.

[2] Dean, University of Kansas City.

[3] Glenn G. Bartle, "The Geology of the Blue Springs Gas Field, Jackson County, Missouri," *Missouri Bur. Geol. and Mines Bien. Rept.* (1933).

has produced 1,697,801,000 cubic feet of gas which is an average of 816,250 cubic feet per acre. The best individual lease has produced from 240 acres an average of 1,521,000 per acre. Production from the East Blue Springs field was in the Squirrel sand at a depth between 250 and 400 feet. The rock pressure above atmospheric at the well-head was 90 pounds initially.

If we estimate the minimum delivery pressure ($\frac{1}{2}$ pound) and the atmospheric pressure (14.4 pounds), we may obtain the volume of the gas in the underground reservoir (816,250 cubic feet per acre divided by 104.4/14.9 equals 116,495 cubic feet). This figure of compressed gas per acre reduced to a square-foot basis (116,495)/43,560 equals 2.67 cubic feet of compressed gas for each square foot of surface average throughout the field.

TABLE I

Field	*Producing Formation*	*Total Production (1,000 Cubic Feet)*	*Production per Acre (1,000 Cubic Feet)*	*Compressed Gas in Reservoir per Square Foot (Cubic Feet)*	*Average Thickness of Gas Sand (Feet)*	*Effective Porosity (Per Cent)*
Blue Springs East and Northeast	Squirrel	1,697,801	816	2.67	22.8	11.7
Blue Springs West	Squirrel	3,585,991	734	2.10	26.1	8.0
Blue Springs South	Channel	227,509	406	1.86	26.7	6.9
Sni-a-Bar	Upper Bartlesville	982,520	1,907	4.05	21.6	18.7

Two and two-thirds cubic feet of gas under each square foot of this field might be contained in any relatively thin porous formation. To get the true porosity of the formation, it is necessary to know the thickness of the gas-bearing part. Fortunately, it is the common practice of the drillers to continue drilling into the gas-bearing formation as long as the open flow continues to increase. In places a hard layer of the sand is encountered and no increase can be noted. Commonly this hard layer is at the top of the Squirrel horizon, but it may be in the middle of the gas. Drilling below the gas is discouraged for fear that water will be encountered.

In the East Blue Springs field, 49 wells which bore gas from the Squirrel horizon showed gas-bearing sand between 7 and 42 feet in amount with an average of 22.8 feet. If we divide 2.67 (cubic feet of

compressed gas) by 22.8 (feet average gas-bearing sand) we obtain 11.7 per cent, which is the percentage of the effective porosity. The amount of Squirrel sand which was drilled in addition to the gas-producing formation varied greatly to a total of 68 feet. It is obvious that most of the Squirrel formation, even over the gas field, was not gas-bearing, being either dry and non-porous, or low and full of water.

The West Blue Springs field, sometimes known as the Bannister Ridge field, has produced 3,585,991,000 cubic feet from 4,880 acres, an average of 734,834 cubic feet per acre. Production is from the Squirrel sand at a slightly greater depth than in the East Blue Springs field, and the initial rock pressure was 105 pounds. Estimating the minimum delivery and atmospheric pressure as before, we obtain the volume of 91,739 cubic feet of compressed gas per acre, or 2.10 cubic feet for each square foot of surface.

An analysis of the logs of 156 wells shows an average of 26.1 feet of gas-bearing sand, in addition to the non-producing sand in the same formation which was as great as 40 feet in some wells. In order to hold 2.10 cubic feet of compressed gas under each square foot of surface with an average gas-bearing sand of 26.1 feet, an effective porosity of only 8.0 per cent is required.

In the South Blue Springs field, sometimes called the Lee's Summit field, the production is from the Channel sand. This is the unconformable basal sandstone of the Missouri series occurring within the Pleasanton of Missouri or at the base of the Bourbon formation of the Missouri series, according to the Kansas classification.[4] The Channel sand corresponds with the Warrensburg-Moberly sandstone at the outcrop in Missouri, with the Big Lake sand of the Paola, Kansas, district, and probably with the Cleveland sand of Oklahoma.

A great thickness of Channel sand was encountered in the wells which were drilled through this formation: 147 feet in one, 145 feet in another, 152 feet in the third. After gas was found, most of the wells were drilled only into the top of the Channel sand, continuing as long as the gas continued to increase. Twenty-eight of these wells showed an average thickness of gas-bearing formation of 26.7 feet. In spite of the thickness of this sand, the total recovery of this field was 227,509,000 cubic feet over 1,560 acres, or an average recovery per acre of 406,000 cubic feet. With an initial pressure of 60 pounds, this is the equivalent of 81,362 cubic feet of compressed gas per acre, or 1.86 cubic feet of compressed gas for each square foot of surface. If we compare this figure with the 26.7 feet of gas-bearing sand, we obtain 6.9 per cent effective

[4] R. C. Moore, "Stratigraphic Classification of the Pennsylvanian Rocks of Kansas," *Kansas Geol. Survey* (1936).

porosity. It is apparent that this great thickness of sand is also mainly full of water and that the effective porosity of the Channel sand is an even lower figure than in the case of the Squirrel sand.

Immediately east of Kansas City and southeast of Independence is a different type of gas field called the Sni-a-Bar Shoestring. The typical part of this field is a little more than 5 miles long but only 700–900 feet wide. Production is from the shoestring sand in the Cherokee formation known locally as the upper Bartlesville. The stratigraphy of parts of this field has been described by the writer[5] and by Frank C. Greene of the Missouri Geological Survey.[6]

Due to competitive drilling on small tracts and competitive pipeline facilities, 47 gas wells have been drilled on this shoestring, although the total area drained is only about 515 acres. These wells were connected with a market about the first of the year 1938, and in the short time since that date have been largely exhausted, if not within one per cent, as in the Blue Springs field, at least within the last 5 per cent. The depth of these wells is between 450 and 550 feet, the initial rock pressure 147 pounds, and the largest wells had an initial flow of about 4 million cubic feet.

Production from the 515 acres now totals 982,520,000 cubic feet, an average of 1,907,805 cubic feet per acre. Estimating the delivery and atmospheric pressure as before, we may reduce the volume to 176,648 cubic feet of compressed gas per acre, or 4.05 cubic feet of compressed gas for each square foot of surface.

An analysis of the logs of these forty-seven wells shows an average of 21.6 feet of gas-bearing sand in this upper Bartlesville horizon. In order to hold 4.05 cubic feet of compressed gas in 21.6 cubic feet of gas-bearing sand, an average porosity of 18.7 per cent is necessary. This percentage is less surprising and more satisfactory than the percentage in the other fields studied in this county. As in the other fields, however, it is probable that a considerable thickness of unproductive sand is to be found below the total depth of these wells.

It seems that all of these figures for effective porosity are comparatively small. Of course they represent an average over the whole field, and the top of the structures produce much more per acre, which may be accounted for by either the higher porosity of the sand, or the greater thickness of the gas-bearing sand, or both. It will be remembered that these figures from 1.86 to 4.05 cubic feet of solid gas per

[5] Glenn G. Bartle, "Subsurface Study of Cherokee Formation near Kansas City, Missouri," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 22, No. 7 (July, 1938), pp. 918–24.

[6] Frank C. Greene, "Oil and Gas Developments in Missouri in 1933–34," *Missouri Bur. Geol. and Mines Bien. Rept.* (1935).

square foot of surface in these fields represent the amount actually produced. While conditions of operation were almost ideal for the recovery of a large percentage of the total of the underground reserve, it is not claimed that this was the total underground reserve.

It is interesting to note that comparatively thin sands of low porosity will still yield gas in quantities which are profitable.

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REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and available, for loan, to members and associates.

SUBSURFACE MISSISSIPPIAN ROCKS OF KANSAS, BY WALLACE LEE

REVIEW BY HUGH McCLELLAN[1]
Wichita, Kansas

"Subsurface Mississippian Rocks of Kansas," by Wallace Lee. With report on fossils by Geo. H. Girty. *Kansas Geol. Survey Bull. 33* (1940). 114 pp., 10 pls., 4 figs.

This report is one of seven Kansas State Geological Survey Bulletins bound in one volume. These are: *Bulletin 27*, "Ground-Water Resources of Kansas"; *Bulletin 28*, "Oil and Gas in 1939"; *Bulletin 29*, "Asphalt Rock"; *Bulletin 30*, "Oil and Gas in Lynn County"; *Bulletin 31*, "Oil and Gas in Montgomery County"; *Bulletin 32*, "Coal Resources"; *Bulletin 33*, "Mississippian Rocks of Kansas."

This bulletin is the result of a coöperative project of the Kansas State Geological Survey, and the United States Geological Survey. After 4 years of study, Wallace Lee has produced a very important addition to the knowledge of the subsurface stratigraphy of Kansas.

The author states that "the investigation was undertaken to determine the relations of the features of the Mississippian rocks to the oil and gas deposits of the state." In 1939 an advance report was published as *Bulletin 26*, containing a map showing thickness of Mississippian limestone and relation of thinning of the limestone to the oil pools in the state. The present work is concerned chiefly with the stratigraphy and distribution of the Mississippian rocks.

By means of microscopic examination of cuttings and cores, and of insoluble residues, the Mississippian in Kansas is divided into thirteen formations, eight of which are correlated with, and bear the names of, formations found in Missouri. Three formations are correlated with rocks found in Iowa, Oklahoma, and Arkansas, and two exclusively subsurface formations are named the Watchorn and Cowley. At least six unconformities are mentioned within the Mississippian.

The term "Chattanooga shale" is used to designate the lower Mississippian shale, now generally called Kinderhook shale where found in its greenish phases. Lee divided the upper Kinderhook into two formations, the lower member being the Compton limestone, and the upper member the Northview shale, both correlative with the Chouteau limestone of Missouri. South of the Central Kansas uplift there is a similar sequence which is correlated with the St. Joe formation. Plate 3 is a thickness map of the Chattanooga shale, which clearly indicates that the Nemaha Mountains did not exist at that time. Some light is thrown on the age of the Central Kansas uplift by the map, which shows a consistent thinning toward the west, and in the fact mentioned by the author, of the overlap of the Mississippian limestones beyond the edge of

[1] Manuscript received, March 26, 1941.

the Chattanooga shale northeast and southwest of the uplift. The Compton and Northview formations, however, are not found west of the Nemaha range, and Lee believes that the basin was limited on the west by minor pre-Chouteau folding along the Nemaha axis. This is new evidence on the old question of the date of origin of the Nemaha granite ridge. Plate 4, showing the generalized topography of the pre-Chattanooga terrane, indicates that several streams flowed north into the North Kansas basin through wide valleys, some of which followed the outcrops of Maquoketa shale on the north and east flanks of the Central Kansas uplift. The author points out that the Chattanooga shale filled these depressions, ending with a nearly flat surface. Many geologists who have worked in the Seminole district of Oklahoma will remember the same phenomenon encountered there in the Woodford formation.

The Gilmore City limestone formation, of uppermost Kinderhook or lower Osage age, was identified northeast and southwest of the Central Kansas uplift, and is correlated with the formation of that name found in the Gilmore City basin of western Iowa. Lee postulates a continuation of the Gilmore City basin toward the southwest, crossing the Central Kansas uplift. This is based on rather sparse control, consisting of seven wells in about half of Kansas, and one well in Yuma County, Colorado. Identification was based on the microscopic examination of well cuttings and siliceous residues. The early existence of the Central Kansas uplift is admitted by most geologists, and to the reviewer it does not seem probable that there was a basin in late Kinderhook time with the axis crossing Norton and Phillips counties in a southwesterly direction. However, there is no evidence to prove that the basin did not cross the axis of the Central Kansas uplift at some low point farther northwest.

Oil geologists will be interested in the newly named formations, the Cowley, assigned to the lower Meramec, and the Watchorn, lying above and separated from it by the Warsaw limestone.

The pre-Cowley surface is described as "the northern part of a large erosion basin lying chiefly in Oklahoma." In Chautauqua and Cowley counties the base of the Cowley formation is below the top of the Chattanooga shale and toward the west it overlaps all the other beds of upper Kinderhook and Osage age. The formation consists of dark and gray silty dolomite, dark and cherty dolomite and limestone, very glauconitic at the base.

The Watchorn formation is defined as all the limestone which overlies the Cowley and Warsaw formations and which unconformably underlies the Pennsylvanian rocks in the Watchorn Oil and Gas Company's Morrison well No. 1, Sec. 17, T. 32 S., R. 21 W., Clark County, Kansas. Identification is based on lithological characteristics and on an examination of fossils by G. H. Girty. Girty identifies the lower 268 feet as of Meramec age, probably Spergen and Warsaw, but no fossils were found in the upper 359 feet. There is thus still room for the belief of a number of geologists that rocks of Chester age are present in this well and westward into Colorado, although Lee does not agree with this idea, while admitting its possibility.

In summation it may be said that Wallace Lee has produced the most thorough and comprehensive report on the subsurface phases of the Mississippian rocks yet written. He has provided the oil geologist with some very valuable information, which will both assist and inspire further research in this important subject.

GROUND-WATER RESOURCES OF KANSAS, BY RAYMOND C. MOORE

REVIEW BY HUGH McCLELLAN[1]
Wichita, Kansas

"Ground-Water Resources of Kansas," By Raymond C. Moore. With chapters by S. W. Lohman, J. C. Frye, H. A. Waite, T. G. McLaughlin, and Bruce Latta. *Kansas Geol. Survey Bull. 27* (1940). 112 pp., 28 figs., 34 pls.

In the first section of this bulletin Moore has covered the general subject of ground-water resources briefly but thoroughly in language the layman can understand. The nature and distribution of ground water, the filling of reservoirs and the underground movement of water, as well as the quantity and quality of ground water, are considered. A large amount of data collected by the Survey's own portable rotary drill furnished the facts for many of the conclusions which will be new to most geologists who have not been connected with the study of ground water in Kansas. The water-bearing formations of Kansas are reviewed, and the state is divided into four ground-water regions, based on the quantity and quality of ground water available in each. These regions are subdivided into eighteen districts.

The eastern region, extending as far west as eastern Washington, Harvey, and Sedgwick counties, is characterized by escarpments of westward-dipping Carboniferous and Permian rocks. Except in the larger stream valleys this region is lacking in ground-water reservoirs of large capacity. The north-central Kansas region comprises mainly the area of Cretaceous outcrops. Aside from the Dakota sandstone, which in many places produces highly mineralized water, this region is also lacking in large reserves of ground water. The south-central region includes the outcrops of Permian redbeds, in which nearly all the available ground water occurs in surficial deposits. The western Kansas region, which contains the Ogallala beds, is, for that reason, the most favored area in the state for ground water of high quality and large volume. The McPherson gravel is included in an eastern extension of this division.

The chapter entitled "Ground-Water in the McPherson District, Kansas," by S. W. Lohman, treats only of the occurrence of ground water in the unconsolidated Tertiary and Quaternary beds in the district. Much of the information was obtained from more than 100 test wells drilled in the course of a joint investigation conducted by the Kansas State Geological Survey, the United States Geological Survey, the State Board of Health, and the City of Wichita. A contour map of the ground-water table northwest of Wichita in Sedgwick and Harvey counties will be of interest to geologists. Two cross sections of the water-bearing alluvial deposits of the Emma Creek (Tertiary) and the McPherson (Quaternary) formations give evidence of the detailed work done. The author points out that the McPherson formation (restricted) occupies the channel of an ancient stream which once connected the Smoky Hill and Arkansas rivers. A glance at the cross sections reveals that this stream cut entirely through the Emma Creek formation and, as in California and elsewhere, the Quaternary gravels lie at a lower elevation than the Tertiary gravels. The yield of wells from the McPherson formation and the Arkansas

[1] Manuscript received, March 26, 1941.

River gravels has reached, in several instances, 2,000 gallons per minute, but the Emma Creek formation is, in general, only a fair water producer.

In Ford County, as reported by H. A. Waite, most of the wells derive water from the Ogallala and Dakota sands. It is interesting to note that several samples of water analyzed show a fluoride content exceeding 1.5 parts per million, which is sufficient to cause some damage to children's teeth.

The bulletin closes with a number of photographs illustrating ground-water measurement and ground-water producing formations.

One feels that more space could have been devoted to the consideration of the application of ground-water information to the problem of the pollution of ground-water reservoirs by oil-field brines. It is mentioned briefly on page 33. However, petroleum geologists operating in Kansas can gain much of value by reading this bulletin and drawing their own conclusions therefrom.

PETROLEUM AND GENESIS OF THE THIRD BRADFORD SAND, BY PAUL D. KRYNINE

REVIEW BY PARKE A. DICKEY[1]
Pleasantville, Pennsylvania

"Petrology and Genesis of the Third Bradford Sand," by Paul D. Krynine. *Pennsylvania State College Min. Indus. Exper. Sta. Bull. 29* (1940). 134 pp.

Dr. Krynine presents here the results of a very thorough petrographic study of the Bradford Third sand. It is a brilliant piece of research, and work of this type will assist greatly in the solution of the problems of stratigraphy in Pennsylvania. The careful identification of the heavy minerals and rock fragments in the Bradford Third sand should be very helpful in the correlation of the Upper Devonian oil and gas sands, and help to trace their history.

On the other hand, some of the broad and sweeping conclusions in regard to the conditions of sedimentation and orogenic history of the Appalachian region are based on such vague evidence as to detract from the value of the work as a whole. Apparently little or no consideration is given to the evidence afforded by the actual regional stratigraphic and structural relations of the rocks.

Dr. Krynine made systematic petrographic studies of diamond-drill cores from six wells in the Bradford field, and also studied samples from sixteen other wells in the pool, besides many samples from other districts. A complete picture of the pool could hardly be obtained from the study of twenty-two wells, and insufficient credit is given to the more comprehensive work of C. R. Fettke.[2]

The Third Bradford sand (which should have more properly been called the Bradford Third sand to differentiate it from a gas sand of the central and southern districts) is medium- to fine-grained sandstone with subordinate siltstone and shale layers. It contains as much as 30 per cent rock fragments, principally low-rank metamorphic rocks, phyllites, slates, some schists and

[1] Manuscript received, March 29, 1941. Published by permission of the State geologist.

[2] C. R. Fettke, "The Bradford Oil Field," *Pennsylvania Topog. and Geol. Survey Bull. M 21*. Harrisburg (1938).

quartzites. For this reason Dr. Krynine calls it graywacke, although the use of the term might be questioned. Definitions of the term differ markedly. Holmes[3] applies it to "feldspathic or tuffaceous grits and coarse sandstones," and Milner[4] defines it as "a sandstone compounded of quartz and miscellaneous rock particles of diverse origin, the latter often in excess of the detritial quartz." Twenhofel[5] says that a graywacke is "the basic equivalent of arkose and is composed of little-decomposed particles derived from basic igneous rocks and their metamorphic equivalents, thus having a large content of ferromagnesian minerals," and adds in a footnote, "the term has been used for fine-grained dark sandstones in which considerable argillaceous matter is present and for dirty sandstones that have experienced some degree of metamorphism." The Bradford sand does not fit exactly any of these very diverse definitions.

Dr. Krynine attributes the brownish color of the sandstone to weathering on the outcrop or oxidation of the cores. Geologists who have spent many field seasons in the district have not definitely identified any outcrop as Bradford Third sand horizon, much less the Bradford sand typically developed. The term "chocolate brown" was applied by the drillers, and accurately describes the color of the fresh drillings and cores in nearly all parts of the field.

The excellence of the work is principally in the thoroughness of the heavy-mineral studies. The quartz is divided into four types of igneous quartz, three varieties of metamorphic quartz, and secondary silica. Other minerals are similarly divided, especially tourmaline, of which thirteen varieties are recognized. The heavy minerals comprise four suites: (1) a metamorphic suite; (2) a suite consisting of well rounded tourmaline and zircon, the tourmalines commonly having authigenic overgrowths on well rounded grains, which are characteristic of the Cambrian quartzites; (3) different types of tourmaline and zircon that appear to have come from low-rank metamorphic rocks; and (4) a nondescript group comprising various authigenic minerals as well as allogenic minerals whose provenance is not clear.

Twenty-eight mechanical and mineralogical analyses are given, but the author points out, quite justly, that errors in sampling and the effect of breaking grains in laboratory procedure do not warrant the refinement to which many of the mechanical analyses have been carried. An excellent description of the different rock types in the sand body is given. It might be questioned whether the Bradford sand is "homogeneous in its heterogeneity" as the author states. Many of the other Pennsylvania oil sands are more heterogeneous than the Bradford sand, yet they show very marked patterns in the shape of the lenses and the distribution of coarse and fine material. Fettke's study[6] indicates that the same may be true of the Bradford sand. The study of thousands of well records is necessary to work out these patterns.

The difficult and complex subject of texture and pore pattern is well handled, but from the point of view of a petrographer and not a petroleum engineer. Although the section is subtitled "The System Sandstone-Oil-Water (or Air)," little that is helpful is given on the relation between the

[3] Arthur Holmes, *The Nomenclature of Petrology*, 2d ed. London (1928), p. 113.

[4] Henry B. Milner, *Sedimentary Petrography*, 2d ed. London (1929), p. 281.

[5] W. H. Twenhofel, *Principles of Sedimentation* (1939), pp. 289–90.

[6] C. R. Fettke, *op. cit.*, p. 227.

fluids and the surfaces. One might gather from reading the discussion that the author thinks that the clay material in the sand is naturally dry, instead of being, at least in part, wet with connate water. He fails to point out that the swelling and alteration of the clays can not be due to the flood water, but is due to the reduced salinity of the flood water.

The author shows conclusively that the low-rank metamorphic rocks of probably Ordovician (possibly pre-Cambrian) age provide a good part of the material of the Bradford sand. Other sources were the older Paleozoic quartzitic sandstones, and in smaller amount the crystalline high-rank metamorphic rocks of eastern Pennsylvania. He states that the material forming the Bradford sand was transported only a short distance, probably much less than 200 miles and possibly only a small fraction of this figure. He does not state where the low-rank metamorphic rocks were exposed to erosion during Upper Devonian time. The nearest outcropping areas of these rocks must have been, at the very least, 200 miles from the Bradford district, and transportation must have occurred across the Catskill delta plain. No great hiatus involving the Devonian is known to exist in Pennsylvania northwest of the Piedmont, and it certainly does not exist southeast of Bradford as far as the Cumberland Valley for the section is everywhere well exposed and completely developed.

Dr. Krynine concludes that the Bradford sand was deposited in a delta which he compares with the Mississippi delta. This idea is not new, and was advanced by Dr. Fettke in 1934.[7] More recent studies have caused Dr. Fettke[8] to change his opinion, and he now believes that the Bradford sand, like some of the shallower oil sands of northwestern Pennsylvania, was deposited off the old shore by marine rather than fluvial currents.

The history of the deposition of the Appalachian sediments is not clear as Dr. Krynine appears to think. The idea that orogeny took place off and on, during the whole Paleozoic, is not new with him, and is indeed obvious from the succession of great conglomerates and continental strata from the basal Silurian through the Pennsylvanian. Most geologists will grant that the upper Paleozoic sandstones (all of which Krynine prefers to call quartzites or graywackes) were largely derived from pre-existing sediments. Some, perhaps, will not admit that all can be traced ultimately to the Cambrian quartzites.

Dr. Krynine's paper contains abundant tables and charts and a few line drawings. The photomicrographs are clear and well reproduced. The editing, printing, and make-up are good except for a few typographical errors. The reviewer considers the petrographic work an outstanding contribution to the geology of Pennsylvania, but its value as a contribution to petroleum technology is less easily recognized. The conclusions concerning stratigraphy and structure are not sufficiently substantiated, and probably can not be by purely petrographic studies.

[7] C. R. Fettke, "Physical Characteristics of Bradford Sand and Relation to Production of Oil," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 2 (February, 1934), p. 208.

[8] *Idem*, "The Bradford Oil Field," *Pennsylvania Topog. and Geol. Survey Bull. M 21* (1938).

TEMPERATURE, ITS MEASUREMENT AND CONTROL IN SCIENCE AND INDUSTRY, A SYMPOSIUM

REVIEW BY ROGER C. WELLS[1]
Washington, D. C.

Temperature, Its Measurement and Control in Science and Industry. Papers presented at a symposium held in New York City, November, 1939, under the auspices of the American Institute of Physics with the coöperation of the National Bureau of Standards and the National Research Council. 1362 pp. Reinhold Publishing Corporation, 330 West Forty-Second Street, New York (1941). Price, $11.00.

This book is a monumental work on temperature as it affects many fields of natural phenomena and man's activity. It consists of 13 chapters, embracing 130 separate papers by different authors, the preparation of which involved coöperation with the American Ceramic Society, the American Chemical Society, the American Institute of Mining and Metallurgical Engineers, the American Society of Mechanical Engineers, the American Society for Metals, the American Society of Heating and Ventilating Engineers, the American Society of Refrigerating Engineers, the American Society for Testing Materials, the American Standards Association, the American Welding Society, the Society of Automotive Engineers, and the American Foundrymen's Association through committees and sub-committees.

The geologist may pause to note among other things the relation of temperature to biology, its bearing on life, animals, plants, bacteria, vital processes, its regulation in animals, and its control for living, but his attention will fall more particularly on the geophysical information on the one hand or on oil problems on the other.

Chapter 4 is devoted to the natural sciences. J. B. Kincer writes of the distribution of temperature over the earth's surface, marine, continental and mountain climate, diurnal and annual ranges, temperature trends, departures from normal, and similar statistical information. At the present time we are living in an abnormally warm epoch, a trend that has been general over the globe. N. L. Bowen discusses "geologic thermometers." These are mostly materials that undergo phase changes or inversions with temperature. Such changes, unfortunately, are affected by pressure and differences in solutions. Magmas have probably seldom been above 1,200° C. Pegmatites have probably formed at approximately 573° C. The reheating of buried sediments has probably never exceeded 1,150° C. E. G. Zies outlines the methods used in measuring temperatures at hot springs, geysers, fumeroles, and volcanoes, employing thermometers, thermocouples, and optical pyrometers. C. Harmantas and H. R. Byers describe the measurement of upper-air temperatures, and G. P. Kuiper that of stellar temperatures. The reviewer could find no reference to glaciers as indicators of climate and the word ecology is apparently not used in the book.

Chapter 7 is devoted to automatic temperature regulation and recording. Among others C. L. Thomas and Gustav Egloff describe a high-temperature

[1] Chief chemist, United States Geological Survey. Manuscript received, April 24, 1941.

thermostat, based on the use of a metal block, that is useful in the study of thermal and catalytic reactions of hydrocarbons. Paul Wing, Jr., and N. A. Miller discuss high-speed temperature measurement in petroleum refining, as used in the control of catalytic processes of refining and treating oils. F. A. Brooks and others describe the determination of soil and air temperatures by means of multiple thermocouples, as applied in a citrus grove during nocturnal frosts.

Chapter 8 gives a number of special applications and methods, such as thermometry in hygrometry, dew-point recorders, psychrometers, and anemometers. The control and measurement of temperature under the microscope are described in detail by C. P. Saylor, who refers to the researches of Miss Taisia Stadnichenko on oil-shale and coal. Suitable substances for calibrating such apparatus are noted. For moderately high temperatures silica covers must be used in place of ordinary cover glasses. C. G. Abbot describes the measurement of solar and stellar energy. Bernard Lewis and Guenther von Elbe consider the temperature of flames produced by fuels in heating and generating power. In flames the temperature defines a state of statistical equilibrium of the gas molecules, but objects in flames are generally at lower temperature owing to loss by radiation. C. F. Squire explains the principles of magnetic cooling below 1° K. W. M. Cohn gives melting points of some refractory materials and describes the production of high temperatures in small furnaces.

In Chapter 9, on general engineering, J. G. Bennett and M. Pirani report on the measurement of gas temperatures and M. A. Mayers describes measurements with large probes in stoker fuel beds.

Chapter 11 is devoted to the oil industries. W. D. Mounce discusses in a general way the problems attending temperature measurements in oil wells and M. C. Terry and J. H. Burney describe thermal prospecting. C. E. Van Orstrand describes his apparatus, shows temperature contours in typical fields, gives the gradients observed in 128 oil fields and discusses certain theoretical aspects of earth temperatures. He concludes that temperatures in oil fields are dependent largely on four factors: (1) configuration of the strata; (2) thermal conductivities; (3) depths of basement rocks; and (4) sequence of geological events. Radioactivity may cause a small part of the temperature observed in sediments arched over granite ridges. R. W. French also discusses temperatures in oil wells and M. T. Halbouty their effect on drilling, production, cementing operations and the deposition of paraffine. Halbouty gives thermal gradients in the Texas and Louisiana fields. The last three papers, like most of the other papers in this volume, are followed by fairly complete bibliographies. The other papers in this chapter deal with the rôle of temperature in welding casing, control in processing operations, the critical temperature of mixtures, measurement of metal temperatures in cracking still tubes, the design of thermocouples for experimental cracking stills, and temperature control in oil-storage losses.

The other chapters in the book deal with theories, education, and applications to different fields of less immediate interest to geologists. Enough has been given to suggest the wide range covered. Aside from the methods described the book contains much information on geophysics and geochemistry. It appears to be by far the best compendium of its kind in existence; in fact there is nothing comparable with it in range of subject matter. It is well

printed and well bound. An appendix includes a number of useful tables and a glossary of terms.

THE THEORY OF GROUND-WATER MOTION, BY M. KING HUBBERT

REVIEW BY L. K. WENZEL[1]
Washington, D. C.

"The Theory of Ground-Water Motion," by M. King Hubbert. *Jour. Geol.*, Vol. 48, No. 8, Pt. 1 (November–December, 1940), pp. 785–944.

In "The Theory of Ground-Water Motion" Dr. Hubbert presents a stimulating and controversial contribution to the fast-growing bibliography on permeability of rocks and laminar flow of fluids. The abstract of the paper states in part:

> The existing analytical treatments of ground-water flow have mostly been founded upon the erroneous conception, borrowed from the theory of the flow of the ideal frictionless fluids of classical hydrodynamics, that ground-water motion is derivable from a velocity potential. This conception is in conformity with the principle of the conservation of matter but not with that of the conservation of energy. In the present paper it is shown that a more exceptionless analytical theory results if a potential whose value at a given point is defined to be equal to the work required to transform a unit mass of fluid from an arbitrary standard state to the state at the point in question is employed.

This direct statement naturally places the paper in a somewhat contentious category, at least for the present, especially since most of the results given by the author differ very little or not at all from those given by other investigators. Parts of the paper imply that certain fundamental concepts of the ground-water hydrologists, such as those concerning the water table, are in error. The bases for these implications appear to be chiefly a difference of opinion as to the proper definition of ground-water concepts, rather than the concepts themselves, and an unfamiliarity with ground-water literature. Thus, from the standpoint of the ground-water hydrologist parts of the paper may appear to be pedantic.

Dr. Hubbert first discusses the Darcy experiment and the physical significance of Darcy's law. The ground-water hydrologist has sometimes used the term "pressure" to denote the concept sometimes expressed as "total head," or "potential," and has, therefore, stated that water flows from a point of high pressure to a point of low pressure. Hubbert takes exception to the use of pressure in this sense and shows that water may flow from a point of low pressure to one of high pressure—when pressure is defined as a component of the total head. Hubbert writes

> —any statement wherein the rate of flow is assumed to be proportional to the pressure gradient, when dealing with ground-water problems, is to be ruled out on the grounds of being physically erroneous.

Whether or not this statement is true depends on the definition of the term pressure.

Hubbert next makes an analysis of the parameter K (coëfficient of permeability) and reaches the conclusion of Muskat and others that in order to depend only on the properties of the medium the coëfficient of permeability

[1] United States Geological Survey. Manuscript received, May 2, 1941.

should not include factors for density and gravity or for the viscosity of the fluid.

The range of validity of Darcy's law, Darcy's law for gases, flow through extensive media, application to fluid flow, and the relation between the potential field and the flow field are taken up in order. Hubbert discusses the refraction of flow lines across boundaries between different media and points out that the flow lines through anisotropic media will, in general, be somewhat oblique to the direction of the potential gradient. This is a significant point that has application in ground-water work.

He develops the widely known well-discharge formula, which the Federal Geological Survey calls the Thiem formula, and discusses at length the boundaries between inhomogeneous fluids, including the slope of the interface, the elevation of the fluid interface, and the refraction of a fluid interface across a plane boundary between media of different permeabilities, and points out the application to ground water. Hubbert also takes up the effect of capillarity and the influence of capillarity upon a two-fluid interface.

In a discussion of the water table Hubbert states,

> —the water table represents an elevation below which water flows freely into an uncased hole and above which no such flow occurs. This fact has led, naturally enough, to the conception, also of wide currency among ground-water hydrologists, that the water table underground forms a bounding surface between a lower region which is completely saturated with water and an upper region in which saturation is incomplete.

This statement is somewhat surprising to the ground-water hydrologist inasmuch as Meinzer,[2] in 1923, excluded by definition the capillary fringe from the zone of saturation. Since the capillary fringe may be saturated for some distance above the water table it is obvious that the water table (which is the upper surface of the zone of saturation except where the upper surface is formed by impermeable rocks) does not represent a bounding surface between a lower region which is completely saturated and an upper region in which saturation is incomplete.

Hubbert discusses the effects of temperature and pressure upon fluid properties and compares his theory of ground-water motion with methods used by others. Throughout the paper Hubbert confines his treatment to the steady-state flow of water, to which he states most ground-water problems can be reduced. That somewhat the opposite is true, however, is shown by the many ground-water problems that until recently could not be solved directly, but which now are being attacked by means of the so-called non-equilibrium method developed by C. V. Theis.[3]

In the section on velocity potential Hubbert states that since the classical studies of Slichter most of the authors who have studied the motion of ground water have started by assuming that the potential function sought was a velocity potential. Among the authors mentioned are Slichter, Dachler, Muskat, Gardner, Collier and Farr. Hubbert concludes that

[2] O. E. Meinzer, "The Occurrence of Ground Water in the United States, with a Discussion of Principles," *U. S. Geol. Survey Water Supply Paper 489* (1923). 321 pp. *Idem*, "Outline of Ground-Water Hydrology, with Definitions," *ibid., Paper 494* (1923). 71 pp.

[3] C. V. Theis, "The Relation between the Lowering of the Piezometric Surface and the Rate and Duration of Discharge of a Well Using Ground-Water Storage," *Trans. Amer. Geophys. Union* (1935).

. . . a velocity potential exists only for fields of flow involving a fluid of constant density and viscosity and a medium which is homogeneous and isotropic throughout. Since these several conditions . . . are not even approximately realized . . . in ground water problems . . . , it is clear that the velocity-potential conception of Darcy's law is an inadequate one.

All ground-water hydrologists probably will not, however, agree with this statement.

The piezometric surface, the condition for artesian water, the problem of permeability, and the law of Badon Ghijben and Herzberg are next discussed in some detail. Hubbert points out that the Badon Ghijben-Herzberg law applies only to hydrostatic equilibrium and that for large potential gradients, such as those which occur near a well, a canal, or the seacoast, the use of the law may not give even approximately correct results.

In conclusion Hubbert takes up flow of water near the water table, the Johnson hypothesis of the origin of submarine canyons, and the Florida ship canal. The effect of the construction of the ship canal on the piezometric surface in the Ocala limestone is a matter of much speculation among hydrologists, engineers, and geologists—partly due to a lack of agreement as to the basic data. Hubbert's arguments are unambiguous, but the conclusions reached hinge largely on the validity and applicability of his assumptions.

The entire paper is excellently written with a clear and forceful style. Unlike many other writers on the subject, Hubbert attacks the problem of ground-water motion with a viewpoint unbiased by years of close association with the somewhat idiomatic literature on ground water. As a result, parts of the paper may be criticized by the ground-water hydrologist but these and other parts of the report may be found stimulating since they represent a more or less objective viewpoint on the subject.

METHODS OF STUDY OF SEDIMENTS, BY W. H. TWENHOFEL AND S. A. TYLER

REVIEW BY MARCUS A. HANNA[1]
Houston, Texas

Methods of Study of Sediments, by W. H. Twenhofel and S. A. Tyler. 183 pp. 6×9 inches. 17 figures, and 24 tables. McGraw-Hill Book Company, Inc. (1941). Price, $2.00.

This book, as its title indicates, is a compilation of methods of study of sediments. As stated in the preface, "Sedimentary minerals and rocks are not considered, as the minerals are excellently described by Milner in his *Sedimentary Petrography* and by Krumbein and Pettijohn in their *Manual of Sedimentary Petrography*. Sedimentary rocks have been satisfactorily treated in the *Petrology of Sedimentary Rocks* by Hatch, Rastall, and Black and in works by the senior author."

The book is divided into a Preface, Introduction including "Flow Sheet for Study of Sediments," and eleven chapters. The chapters, including pages, references, tables, and figures, are as follows.

1. The Field Study of Sediments, 16 pp., 4 references
2. Collection of Samples and Specimens. 16 pp., 26 references
3. Preparation of Sediments for Analysis. 10 pp., 26 references

[1] Published with permission of the Gulf Oil Corporation. Manuscript received, May 3, 1941.

4. Mechanical Analysis of Sediments. 21 pp., 32 references, 5 tables, 1 figure
5. Separation of Minerals of Sediments. 30 pp., 41 references, 10 tables, 4 figures
6. Quantitative Determination of Mineral Content. 8 pp., 13 references, 4 tables
7. Graphical Representation of Sediments. 16 pp., 8 references, 4 tables, 8 figures
8. Chemical Methods of Mineral Separation. 13 pp., 29 references
9. Various Physical Properties of Sediments. 20 pp., 33 references
10. Coals. 10 pp., 11 references, 3 figures
11. Thin Sections, Mounting of Mineral Grains, and Peels. 9 pp., 24 references, 1 table

Several types of technique are given with nearly all of the operations discussed. For instance, in discussing the "Collection of Samples from Bottoms of Bodies of Water," chapter 2, several types of sampling apparatus are discussed. They are discussed under: (1) Scraper or Drag-Bucket Type of Sampler; (2) Coring-Tube Samplers; (3) The Snapper or Grab-Bucket Samplers; (4) Rod Samplers; (5) Chambered Weight Samplers; (6) Ripple-Mark Samplers; and (7) Sediment Traps. Several types of samplers are discussed under each heading.

Under the "Heavy-Liquid Separation of Minerals," in chapter 5, all the commonly used liquids are discussed and tables given for the mixing of different liquids to make desired specific gravities. The advantages and disadvantages of each liquid are discussed.

In chapter 7 the various methods of "Graphical Representation of Sediments" are given. Histograms, frequency curves, and cumulative-frequency curves are discussed in considerable detail. Several figures are given to illustrate the discussion.

Under "Staining Methods," chapter 8, several methods are discussed for separation of calcite, aragonite, dolomite, *et cetera.*

These citations are given to illustrate the mass of material which has been assembled. It is difficult in a short review to discuss adequately as many methods and overlapping methods as are given. The subject is well covered and the book will be found helpful to persons studying sediments, either the beginner or the advanced student. Unfortunately there are no illustrations of equipment. However, it would not have been possible to illustrate the equipment sufficiently and yet keep the publication price as low as two dollars. References are given to equipment, and to these the reader is referred. Although the book pertains largely to technique, the authors lend the weight of their experience in selecting a method when several methods are available.

THE RHYTHM OF THE AGES. EARTH HISTORY IN THE LIGHT OF THE PULSATION AND POLAR CONTROL THEORIES, BY A. W. GRABAU

REVIEW BY EDWIN KIRK[1]
Washington, D. C.

The Rhythm of the Ages. Earth History in the Light of the Pulsation and Polar Control Theories, by A. W. Grabau. 561 pp., 25 pls. (Pls. 3–25 in color), 126 text figs. Henri Vetch, the French Bookstore, Peiping, China (1940). Price, $5.00 U.S.

It is difficult to imagine a treatise on historical geology that departs widely from the more or less stereotyped versions of the past. The book here

[1] United States Geological Survey. Manuscript received, May 8, 1941.

noted is such a novelty. It is probable that no one but Grabau could or would have attempted such a task. The work will certainly stand as one of the landmarks of an era wherein the human mind refused to be balked by the complexities of space and time or by conventional strictures. It may well be the last work of its kind for a long time to come.

To many historical geologists a "System" is an objective entity. This idea was probably first suggested by Newberry in his "circles of deposition," though it clearly harks back to the catastrophists of an earlier day. Implicit in a certain school of thought is also the concept of these systems as isochronal chapters in the history of the world. Grabau is one of the exponents of these views and takes Joly's 30 million-year radioactive period as a systemic unit of time.

If we are to have a record of these ideal systems we must have periodic synchronous floodings and drainage of the continental masses throughout the world. Most of the writers rely on positive and negative movements of the land, which is rather difficult to conceive on a grand scale. Grabau assisted by Joly's periodic radioactive fluctuations postulates alternate shrinking and swelling of the floors of the oceanic basins, draining the waters off the lands, or flooding them back as the case may be. As between two assumptions, Grabau's theory would seem simpler and more plausible.

As a corollary to the pulsation theory Grabau rearranges the Paleozoic stratigraphic units into 14 named pulsation periods, and an equal number of named interpulsation periods. In the remainder of the volume he marshals a great amount of evidence drawn from all parts of the world to establish the validity of his theses.

Grabau accepts the theory of continental drift, and it is in the interpretation of the stratigraphic record and its problems in the light of this theory that the book is unique. In the beginning he assumes a continental mass, Pangaea, in the southern hemisphere. Subsequently, there was a fragmentation of this mass and a slow drift of component elements toward and into the northern hemisphere. Concurrently, there were clockwise and counter-clockwise movements of the land masses. A long series of charts show the position of the pole at different times, and the disposition of the land masses. It is all rather bewildering, but, if one advocates continental drift, one must face complexities hitherto undreamed of. At any rate, one can but admire the mind capable of shifting the embryonic continental masses about so as measurably to fit the pattern of our stratigraphic knowledge.

There are prefatory chapters on the crust of the primitive earth, the pulsation theory, geosynclines, graptolite shales, orogeny, disconformities, and the pre-Cambrian earth. These and other chapters interspersed in later portions of the volume are résumés or elaborations of earlier papers by Grabau, some of which are not readily found in this country. Some of the later chapters not directly expository of the stratigraphic record deal with such diverse subjects as volcanism, orogeny, and the coming of man. Of particular interest is a description of the deltaic deposits of the Huangho. For similar deposits Grabau offers the term "Huangho deposits," which may be found useful. He also proposes the term "Shantung" for a buried monadnock. There are other novel terms, but one must read the book to estimate their values. Correlations as expressed in the charts and text should be taken with a grain of salt, but this is true to a greater or less degree of all correlations.

It is stated that the first edition of the work consists of only 800 copies. Owing to the unsettled conditions in China and elsewhere, it is to be hoped that many copies of the book will find their way to America.

RECENT PUBLICATIONS

ARGENTINA

*"Nota preliminar sobre la hoja geológica 'San Carlos de Bariloche'" (Geology of Carlos de Bariloche, Patagonia), by Egidio Feruglio. *Y.P.F. Bol. Inf. Petrol.*, Vol. 18, No. 200 (Buenos Aires, April, 1941), pp. 27–64; 28 photographs, 2 maps, 2 correlation charts.

CALIFORNIA

*"The Paleontology and Stratigraphy of the Pleistocene at Signal Hill, Long Beach, California," by James H. DeLong, Jr. *Trans. San Diego Soc. Nat. Hist.*, Vol. 9, No. 25 (April 30, 1941), pp. 229–52; 4 figs., 1 chart.

*"Gibson Area, Midway-Sunset Oil Field," by W. T. Woodward. *Petrol. World*, Vol. 37, No. 5 (Los Angeles, May, 1941), pp. 40–42; 4 figs.

COLOMBIA

*"Glaciaciones Cuaternarias en la Cordillera Oriental de la República de Colombia" (Glacial Quaternary in the Cordillera Oriental of Colombia), by Victor Oppenheim. *Rev. Acad. Colombiana Cien. Exact., Fisico-Quimicas Nat.*, Vol. 4, No. 13 (Bogota, December 31, 1940), pp. 70–81; 2 maps, 7 pls. (photographs).

GENERAL

*"Influence of Geophysics and Geochemistry on the Professional Training of Geologists," by W. C. Krumbein. *Mining Technology*, Vol. 5, No. 3 (New York, May, 1941). 11 pp., 1 fig., 1 table. *A.I.M.E. Tech. Paper 1327.*

*"Twenty Years' Progress in the Oil Industry," by L. A. Cranson. *Mining and Metallurgy*, Vol. 22, No. 414 (A.I.M.E., New York, June, 1941), pp. 301–05; 2 figs. Comparison of present practice in exploration and drilling with that of 1920.

*"Exploration of Deep Pays Offers Rich Possibilities," by W. V. Howard. *Oil and Gas Jour.*, Vol. 40, No. 4 (Tulsa, June 5, 1941), pp. 24–26, and 44; 2 photographs, 1 map of United States showing areas of possible and probable oil production.

*"Unconformities Complicate Exploration for Deep Pays," by W. V. Howard. *Ibid.*, pp. 109–14; 3 figs.

ILLINOIS

Oil and gas development maps revised to April 22, 1941.

Carmi (T. 4–6 S., R. 9–11 E., 14 W.)
Clay City (T. 1–3 N., R. 6–8 E.)
Kinmundy (T. 4–6 N., R. 9–11 E., 14 W.)
Noble (T. 1–3 N., R. 9–11 E., 14 W.)
Ramsey (T. 7–9 N., R. 1 W., 1–2 E.)
Shawneetown (T. 7–9 S., R. 9–11 E., 14 W.)
Xenia (T. 1–3 N., R. 3–5 E.)

New oil and gas development maps as of May 20, 1941.

Effingham (T. 7–9 N., R. 6–8 E.)

Eldorado (T. 7–9 S., R. 6–8 E.)

Louisville (T. 4–6 N., R. 6–8 E.)

Pinckneyville (T. 4–6 S., R. 2–4 W.)

Blue-line prints, $0.60 each (stamps not acceptable). Illinois Geol. Survey, 100 Natural Resources Building, Urbana.

KANSAS

*"Northwest Kansas," compiled by *Oil and Gas Journal*, Vol. 40, No. 4 (Tulsa, June 5, 1941). 2 pp. between pp. 96 and 97; 1 areal map and several stratigraphic log sections, in colors.

KENTUCKY

*"Lower Ordovician Found in Laurel County, Kentucky," by W. V. Howard. *Oil and Gas Jour.*, Vol. 40, No. 1 (Tulsa, May 15, 1941), p. 34; 1 cross section.

MEXICO

*"The Middle Permian of Chiapas, Southernmost Mexico, and Its Fauna," by F. K. G. Müllerried, A. K. Miller, and W. M. Furnish. *Amer. Jour. Sci.*, Vol. 239, No. 6 (New Haven, Connecticut, June, 1941), pp. 397–406; 3 figs., 1 pl.

MISSISSIPPI

*"Tippah County Mineral Resources." Geology by Louis Cowles Conant. Tests by Thomas Edwin McCutcheon. *Mississippi Geol. Survey Bull. 42* (University, 1941). 228 pp., 21 figs., 1 pl.

NEW MEXICO

*"Mining, Oil, and Mineral Laws of New Mexico," by Charles H. Fowler and Sterling B. Talmage. *New Mexico Bur. Mines and Min. Res. Bull. 16* (Socorro, 1941). 244 pp.

OKLAHOMA

"Subsurface Geology and Oil and Gas Resources of Osage County, Oklahoma, Part 6, Township 28 North, Ranges 10 and 11 East, and Township 29 North, Ranges 9 to 11 East," by H. B. Goodrich, L. E. Kennedy, and Otto Leatherock. *U. S. Geol. Survey Bull. 900 F* (1940 [1941]), pp. 209–36, Pl. 6. Sold by Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $0.50.

WEST INDIES

Scientific Survey of Porto Rico and the Virgin Islands, Vol. III, Pt. 4, "The Tertiary Foraminifera of Porto Rico," by J. J. Galloway and Caroline E. Heminway. 491 pp., 1 fig., 36 pls. of fossils. Published by the New York Academy of Sciences, Central Park West at Seventy-Ninth Street, New York (April 21, 1941). Price, $2.00.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 25, NO. 7, (JULY, 1941), PP. 1425–1429

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large: If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 25, NO. 7 (JULY, 1941), P. 1430

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

CHARLES T. CASEBEER, Mid-Continent division sales manager for the Lane-Wells Company in Oklahoma City, came to his death by injuries received June 6, 1941, in Olney, Illinois, in an automobile accident.

G. H. CROWL, recently of the department of geology at Rutgers University, will be engaged in graduate study in the department of geology at Princeton University next year.

A joint meeting of the Appalachian Geological Society and the Oil and Gas Section of the Engineers Society of Western Pennsylvania was held in Morgantown, West Virginia, on May 23 and 24. D. E. CONAWAY talked on "The Problems Encountered in Correlated Study of the Mississippian and Upper Devonian Formations in Northwestern Pennsylvania," and SIDMUND HAMMER discussed "A Gravity Profile across the Central Appalachians." The technical session was followed by a dinner at which A.A.P.G. president EDGAR W. OWEN was the speaker. On the morning of the 24th the party viewed a number of exposures on the Chestnut Ridge anticline.

LELAND W. JONES, formerly district geologist for the Ohio Oil Company at Edmond, Oklahoma, is working for the Bryan Petroleum Company, at Tulsa.

FREDERICK G. CLAPP, consulting geologist, 50 Church Street, New York, has located his southwestern office at the New Chickasha Hotel, Chickasha, Oklahoma.

W. ARMSTRONG PRICE, consulting geologist, Corpus Christi, has joined the staff of the 28th Battalion, Texas Defense Guard, as operations officer. The staff position formerly so designated is now known as plans and training officer and carries the grade of First Lieutenant. The duties of members of the Defense Guard do not interfere with the ordinary occupations of members except in times of local emergency.

GEORGE S. BUCHANAN and C. H. HARRINGTON are associated in consulting practice in geology and geophysics at 1524 Esperson Building, Houston, Texas.

JAMES S. KIRKENDALL, of the Amerada Petroleum Corporation, has moved from Bakersfield, California, to Tyler, Texas.

GEO. C. MCGHEE, of DeGolyer, MacNaughton, and McGhee, Dallas, Texas, may be addressed at the Office of Production Management, Room 4072, Social Security Building, Washington, D. C.

JACK M. BARTON, recently at the Peabody Museum, Yale University, may be addressed in care of the Magnolia Petroleum Company, Oklahoma City, Oklahoma.

The Indiana-Kentucky Geological Society held its last meeting of the year at the Lamplight Inn, Evansville, Indiana, Wednesday evening, May 28. EDGAR W. OWEN, president of the A.A.P.G., discussed the current activities of the Association. JAMES A. LEWIS, vice-president of Core Laboratories, Inc., of Dallas, Texas, spoke on the subject, "The Application of Oil Field Core Analysis Data to Productive Problems."

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 25, NO. 7 (JULY, 1941), P. 1431

FIELD TRIP

KANSAS GEOLOGICAL SOCIETY
FIFTEENTH ANNUAL FIELD CONFERENCE, AUGUST 27–31

The Kansas Geological Society announces its fifteenth annual field conference to be held in central and eastern Missouri and western Illinois, August 27 to 31, inclusive. This conference is to be held in coöperation with the University of Missouri, the Missouri Geological Survey and Water Resources, and the State Geological Survey of Illinois.

The conference will study the pre-Pennsylvanian rocks of central and eastern Missouri and the Mississippian rocks in Illinois. Principal attention will be given to the Siluro-Devonian and the Ordovician rocks in Missouri. The conference leaders will be E. B. BRANSON, head of the department of geology at the University of Missouri; H. A. BUEHLER, State geologist of Missouri; and M. M. LEIGHTON, chief of the Geological Survey of Illinois. They will be assisted by H. S. MCQUEEN, assistant State geologist of Missouri, and J. MARVIN WELLER, head of the stratigraphy and paleontology division of the Illinois Geological Survey. The conference will convene at Sedalia, Missouri, and proceed as follows.

First day, Wednesday, August 27.—East and north from Sedalia by way of Boonvile, Arrow Rock, Glasgow, and Fayette to Columbia, Missouri. Section extends from Jefferson City (Arbuckle) through Ordovician, Devonian, and Mississippian to lower Pennsylvanian rocks.

Second day, Thursday, August 28.—South from Columbia along Missouri River, crossing to Jefferson City and returning to Columbia at night. Examine in one outcrop along bluffs of Missouri River a section extending from Mississippian to Ordovician in which there are five unconformities.

Third day, Friday, August 29.—East of Columbia to view westernmost exposure of Plattin. Several new quarries have excellent exposures of Mississippian and Ordovician. Reach St. Louis in evening, probably at a hotel in west end of city near Forest Park.

Fourth day, Saturday, August 30.—North from St. Louis, crossing Cap-au-Gres fault and associated folds. Section from Canadian up to Ste. Genevieve. Stratigraphy of Ordovician, Silurian, and Kinderhook-Mississippian. Stop at Hannibal, Missouri, in evening.

Fifth day, Sunday, August 31.—Cross Mississippi River. Excellent exposures of Kinderhook and other Mississippian formations. Trip ends at Keokuk, Iowa.

Several papers on the stratigraphy and structure including maps and sections of the area will be included in the guide book.

Private automobiles will be used for transportation. If you are unable to bring your own car, the committee will undertake to provide you a seat in the car of another participant.

The registration fee will not exceed $9.00 and includes the price of one copy of the guide book. Additional copies may be purchased for not more than $5.00. All participants must pay the registration fee, no matter how much of the conference they attend.

It is important that the committee be able to make an estimate of the number of participants at the earliest possible date. If you hope to attend, or wish to receive further notices of the conference, write the Kansas Geological Society, 412 Union National Bank Building, Wichita, Kansas.

MINERAL ECONOMISTS NEEDED BY THE GOVERNMENT

The United States Civil Service Commission wishes to call your special attention to the examination announced on June 9, for Mineral Economist. The Government is looking for persons especially qualified in the economic aspects of the mineral industries to do professional research in the fields of minerals, coal, and petroleum. Mineral economist positions pay from $2,600 to $5,600 a year. Because of the need for qualified persons to carry on this important National Defense work, applications will be rated as received at the Commission's Washington office until further public notice.

Applicants for this examination must have completed a 4-year college course with major study in such subjects as geology, metallurgy, mining engineering, economics, or political science. However, persons who have had only 2 years of the college study may substitute 2 years of experience dealing with economic aspects of the mineral industries. In addition, all applicants must have had progressive professional experience dealing with the economics of mineral industries. At least some of this experience must have been in research in either metallic minerals, non-metallic minerals, secondary metallic minerals, coal, petroleum, or general mineral economics. Graduate study in mineral economics or in a combination of mineral economics and general economics may be substituted, in varying degrees, for the experience required.

Mineral economists will plan or conduct professional research in mineral economics dealing with the conservation, utilization, extraction, refinement, marketing, consumption, and foreign and domestic sources, of minerals. This will include the evaluation and interpretation of basic data and the preparation of the results for use or publication, as the case might be. Applicants will not have to take a written test, but they are required to submit a list of whatever writings they have done in the field of mineral economics, and if possible, to submit a copy of at least one research project.

The need for mineral economists is immediate and the Commission wishes to ask your cooperation in this recruiting program to secure persons who are qualified for, and interested in, this type of Government work. Qualified persons should be urged to apply for further information on the examination at any first- or second-class post office, or to write to the Civil Service Commission, Washington, D.C.

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The Society sponsors the Kansas Well Log Bureau which is located at 412 Union National Bank Building.

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Meets the first Friday of every month, 7:30 P.M., Civil Courts Room, Caddo Parish Court House. Special dinner meetings by announcement.

SOUTH LOUISIANA GEOLOGICAL SOCIETY

LAKE CHARLES, LOUISIANA

President - - - - - - - - - W. R. Canada
Stanolind Oil and Gas Company
Vice-President - - - - - - - - P. H. Jennings
Magnolia Petroleum Company
Secretary - - - - - - - - E. M. Baysinger
Box 210
Treasurer - - - - - - - - - Baker Hoskins
Shell Oil Company, Inc., Box 598

Meetings: Luncheon 1st Wednesday at Noon (12:00) and business meeting third Tuesday of each month at 7.00 P.M. at the Majestic Hotel. Visiting geologists are welcome.

MISSISSIPPI

MISSISSIPPI GEOLOGICAL SOCIETY
JACKSON, MISSISSIPPI

President - - - - - - - - Urban B. Hughes
Consulting Geologist, 1205 Tower Building

Vice-President - - - - - - Tom McGlothlin
Gulf Refining Company, Box 1105

Secretary-Treasurer - - - - David C. Harrell
Carter Oil Company, Box 1490

Meetings: First and third Wednesdays of each month from October to May, inclusive, at 7:30 P.M., Edwards Hotel, Jackson, Mississippi. Visiting geologists welcome to all meetings.

OKLAHOMA

ARDMORE GEOLOGICAL SOCIETY
ARDMORE, OKLAHOMA

President - - - - - - - - C. W. Tomlinson
509 Simpson Building

Vice-President - - - - - - Tom L. Coleman
U. S. Geological Survey, Box 719

Secretary-Treasurer - - - - - - - Bob Hancock
Magnolia Petroleum Company, Box 299

Dinner meetings will be held at 7:00 P.M. on the first Wednesday of every month from October to May, inclusive, at the Ardmore Hotel.

OKLAHOMA

OKLAHOMA CITY GEOLOGICAL SOCIETY
OKLAHOMA CITY, OKLAHOMA

President - - - - - - - - John E. VanDall
Magnolia Petroleum Company

Vice-President - - - - - - Clyde H. Dorr
Consulting Geologist, 1801 Petroleum Bldg.

Secretary-Treasurer - - Graydon H. Laughbaum
Sinclair Prairie Oil Co., 703 Colcord Bldg.

Meetings, Ninth Floor, Commerce Exchange Building: Technical Program, second Monday, each month, 8:00 P.M.; Luncheons, every Monday, 12:15 P.M.

SHAWNEE GEOLOGICAL SOCIETY
SHAWNEE, OKLAHOMA

President - - - - - - - - - - M. C. Roberts
The Texas Company

Vice-President - - - - - Robert L. Cassingham
Amerada Petroleum Corporation

Secretary-Treasurer - - - - - Martyna Garrison
Amerada Petroleum Corporation

Meets the fourth Monday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

THE STRATIGRAPHIC SOCIETY OF TULSA
TULSA, OKLAHOMA

President - - - - - - - - - - Jerry E. Upp
Amerada Petroleum Corporation, Box 2040

Vice-President - - - - - - - Wendell S. Johns
The Texas Company

Secretary-Treasurer - - - - - - Floyd L. Swabb
Sun Oil Company, Box 1348

Meetings: Second and fourth Wednesdays, each month, from October to May, inclusive, at 8:00 P.M.

TULSA GEOLOGICAL SOCIETY
TULSA, OKLAHOMA

President - - - - - - - - - John L. Ferguson
Amerada Petroleum Corporation

1st Vice-President - - - - - Louis H. Lukert
The Texas Company

2nd Vice-President - - - - Howard J. Conhaim
Consulting Geologist

Secretary-Treasurer - - - - - - - M. R. Spahr
Box 801, Carter Oil Company

Editor - - - - - - - - - - - Charles Ryniker
Gulf Oil Corporation

Meetings: First and third Mondays, each month, from October to May, inclusive, at 8:00 P.M., University of Tulsa, Kendall Hall Auditorium. Luncheons: Every Thursday (October-May), Michaelis Cafeteria, 507 South Boulder Avenue.

TEXAS

DALLAS PETROLEUM GEOLOGISTS
DALLAS, TEXAS

President - - - - - - Lewis W. MacNaughton
DeGolyer, MacNaughton, and McGhee

Vice-President - - - - - - - - J. A. Lewis
Core Laboratories, Inc., Santa Fe Building

Secretary-Treasurer - - - - - - Fred A. Joekel
Magnolia Petroleum Company, Box 900

Executive Committee - - - - Henry C. Cortes
Magnolia Petroleum Company, Box 900

Meetings: Regular luncheons, first Monday of each month, 12:15 noon, Petroleum Club, Adolphus Hotel. Special night meetings by announcement.

EAST TEXAS GEOLOGICAL SOCIETY
TYLER, TEXAS

President - - - - - - - - - Frank R. Denton
Consulting, 225 Owen Bldg.

Vice-President - - - - - - - - C. I. Alexander
Magnolia Petroleum Company, Box 780

Secretary-Treasurer - - - - - - G. J. Loetterle
Shell Oil Company, Inc., Box 2037

Meetings: Monthly and by call.
Luncheons: Every Monday at 12:00 noon, Blackstone Hotel.

TEXAS

FORT WORTH GEOLOGICAL SOCIETY
FORT WORTH, TEXAS

President - - - - - - - - - - Paul C. Dean
Consulting Geologist, W. T. Waggoner Building

Vice-President - - - - - - - - - C. L. Mohr
Ambassador Oil Corporation

Secretary-Treasurer - - - William J. Hilseweck
Gulf Oil Corporation, Box 1290

Meetings: Luncheon at noon, Worth Hotel, every Monday. Special meetings called by executive committee. Visiting geologists are welcome to all meetings.

HOUSTON GEOLOGICAL SOCIETY
HOUSTON, TEXAS

President - - - - - - - George S. Buchanan
Consulting Geologist, Esperson Building

Vice-President - - - - - - - - A. P. Allison
Sun Oil Company, Box 2659

Secretary - - - - - - - - - Leslie Bowling
Union Oil Company of California
1134 Commercial Building

Treasurer - - - - - - - - - Dugald Gordon
Brokaw, Dixon, and McKee, Gulf Building

Regular meeting held every Thursday at noon (12 o'clock) above Kelly's Restaurant, 910 Texas Avenue. For any particulars pertaining to the meetings write of call the secretary.

NORTH TEXAS GEOLOGICAL SOCIETY
WICHITA FALLS, TEXAS

President - - - - - - - - - - - - J. R. Seitz
Seitz, Comegys, and Seitz, 531 Waggoner Building

Vice-President - - - - - - - J. J. Russell, Jr.
Sinclair Prairie Oil Company
509 Hamilton Building

Secretary-Treasurer - - - - - - - J. M. Clark
Tide Water Associated Oil Company
924 Hamilton Building

Luncheons and evening programs will be announced.

SOUTH TEXAS GEOLOGICAL SOCIETY
SAN ANTONIO AND CORPUS CHRISTI TEXAS

President - - - - - - - - - - Gentry Kidd
Stanolind Oil and Gas Company, San Antonio

Vice-President - - - - - - - - G. B. Gierhart
Humble Oil and Refining Company, Corpus Christi

Secretary-Treasurer - - - - W. W. Hammond
Magnolia Petroleum Company, 1709 Alamo
National Building, San Antonio

Meetings: Third Friday of each month alternately in San Antonio and Corpus Christi. Luncheon every Monday noon at Milam Cafeteria, San Antonio, and at Plaza Hotel, Corpus Christi.

SOUTHWESTERN GEOLOGICAL SOCIETY
AUSTIN, TEXAS

President - - - - - - - - - - H. B. Stenzel
Bureau of Economic Geology

Vice-President - - - - William A. Bramlette
Univ. Texas, Dept. of Geology

Secretary-Treasurer - - - - - - Travis Parker
Univ. Texas, Dept. of Geology

Meetings: Every third Friday at 8:00 P.M. at the University of Texas, Geology Building 14.

WEST TEXAS GEOLOGICAL SOCIETY
MIDLAND, TEXAS

President - - - - - - - - - Robert E. King
Shell Oil Company, Inc.

Vice-President - - - - - - - - Fred F. Kotyza
Tide Water Associated Oil Company, Box 181

Secretary-Treasurer - - - - Walter G. Moxey
Stanolind Oil and Gas Company

Meetings will be announced

WEST VIRGINIA

THE APPALACHIAN GEOLOGICAL SOCIETY
CHARLESTON, WEST VIRGINIA
P.O. Box 1435

President - - - - - - - - - J. R. Lockett
Ohio Fuel Gas Co., Box 117, Columbus, Ohio

Vice-President - - - - - Charles Brewer, Jr.
Godfrey L. Cabot, Inc., Box 348, Charleston, W.Va.

Secretary-Treasurer - - - - - J. E. Billingsley
West Virginia Gas Corporation
Box 404, Charleston, W.Va.

Editor - - - - - - - - - Robert C. Lafferty
Owens, Libbey-Owens Gas Department
Box 1375, Charleston, W.Va.

Meetings: Second Monday, each month, except June, July, and August, at 6:30 P.M., Kanawha Hotel.

THE SOCIETY OF EXPLORATION GEOPHYSICISTS

President - - - - - - - - - H. B. Peacock
Geophysical Service, Inc., Houston, Texas

Vice-President - - - - - - Frank Goldstone
Shell Oil Company, Inc., Houston, Texas

Editor - - - - - - - - - - - R. D. Wyckoff
**Gulf Research and Development Company
Pittsburgh, Pennsylvania**

Secretary-Treasurer - - - William M. Rust, Jr.
Humble Oil and Refining Company
Box 2180, Houston, Texas

Past-President - - - - - - - - W. T. Born
Geophysical Research Corporation
Box 2040, Tulsa, Oklahoma

Business Manager **- - - - - - - - J. F. Gallie
P.O. Box 777, Austin, Texas**


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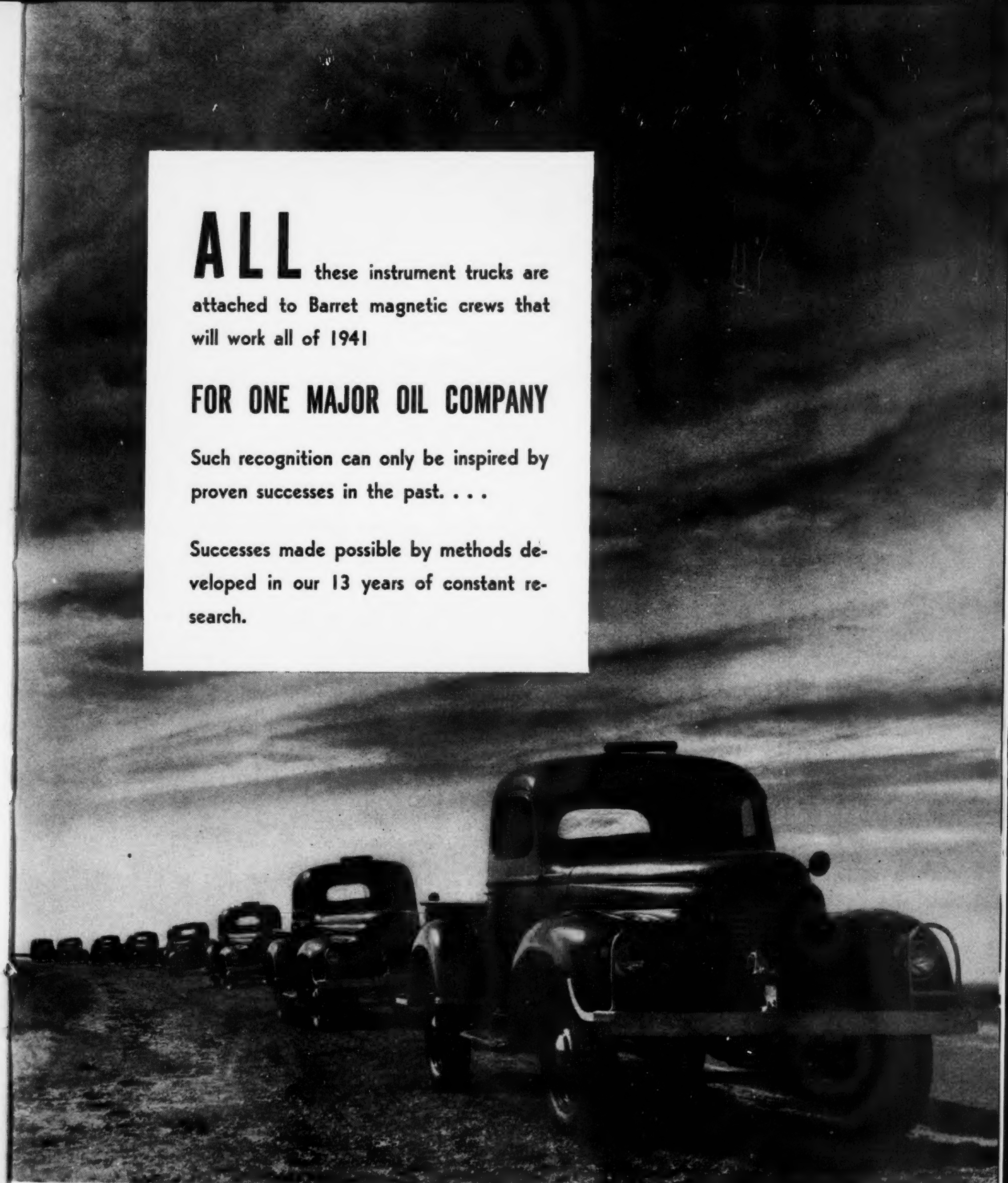
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